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Synthesis of machine - tool racking using a genetic-morphological approach

Kuznetsov Yurii Nikolayevich, El-Dahabi Farouk Wahid

National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"¹
Department of mechanic, Faculty of Engineering, Lebanese University, Tripoli, Lebanon,²

E-mail: info@zmok.kiev.ua, farouk.dahabi@ul.edu.lb

Abstract. A fundamentally new methodological approach to the creation of progressive machine-tool equipment is proposed when considering a material point as a carrier of genetic information in the synthesis of technical systems of the "object" type. The main attention is paid to the search for new technical solutions with the use of tangential clamping, which allows one movement to simultaneously clamp several cutting tools offset from the axis of rotation, for example, in the form of carbide non-regrowth inserts.

KEY WORDS: MATERIAL POINT, GENETIC FORMULA, MORPHOLOGICAL MODEL, CUTTING TOOL, CLAMPING PRINCIPLE

1.Introduction.

Creation of new developing technical systems (TS) require further improvement of their subsystems. At present, the search for new solutions is not possible without an interdisciplinary approach and the use of the latest scientific advances in various fields, combined in the form of NBICSE (nano-bio-info-cogno-socio-eco) - technologies and using artificial intelligence [1,3,7,8,12,16,17]. The challenges of "INDUSTRY 4.0" [6,11] are mainly focused on artificial intelligence, full automation using robots, robotic systems, communications, the creation of intelligent production of a new generation while achieving the following main goals: 1. Increased productivity. 2. Improving product quality. 3. Reducing the cost of environmentally friendly production while saving energy and material resources. 4. Improvement and decrease in the proportion of physical labor. 5. Facilitation and reduction of monotonous intellectual work. 6. Expansion of technological and functional capabilities of equipment. This determined the global trends in the development of mechanical engineering [9,22].

2.Research goal.

Studying and analyzing the stages of the evolutionary development of technical systems (TS) and the principles of creative thinking, substantiate the effectiveness of the new ideology of designing machine-tool equipment, providing for the use of a genetic-morphological approach with the basic genetic principle "from simple to complex" [2,12].

3.The essence of the proposed scientific approach.

The idea is that the main creator is Nature with all objective laws and phenomena, partially discovered by Man, who is an unsurpassed creation of Nature and a creator in his own likeness [12, 14]. This determined the paradigm (postulate) of a new scientific approach - from living Nature to the creation of anthropogenic systems [2,4,15]., which include static and dynamic machine, electrical, construction vehicles, thanks to the intellect of Man, which is declared in the philosophical ideas and prophecy of Acad. V.I. Vernadsky: "With the appearance on our planet of a living creature gifted with intelligence, the planet passes into a new stage in its history. The biosphere passes into the noosphere (the sphere of reason) ... We are just beginning to create an irresistible power of scientific thought, the greatest creative power of Homo Sapiens, a human free personality, the greatest known manifestation of its cosmic power, the kingdom of which is ahead"[5].

The creation of new developing TS is impossible without analyzing and taking into account the accumulated human experience, which, like genetic information on various carriers, is transferred from generation to generation. The history of the development of human society and the evolution of technology have always been associated with mechanics [9]. The main feature of recent decades is the comprehension of the development of modern super technologies for solving not only technical, but also social, environmental, spiritual, psychological and cultural problems, research on which is of an interdisciplinary nature [24]. Genetics and cybernetics, previously subjected to devastating criticism, paved the way for knowledge and their interdisciplinary

use in the creation of new techniques and new technologies [3, 15, 21].

By analogy with the proposed prof. Shinkarenko V.F. a periodic system of electromagnetic elements (primary sources of the electromagnetic field), called the electromagnetic gene, and thanks to the principles of self-organization and the genetic principle "from simple to complex" [19-21], a new view of the material point as a carrier of genetic information when creating a TS of the "object" and "process" type is proposed [10, 18]. This material point at the genetic level is conventionally called a mechanical gene and carries information about translational and rotational movements, loads and their directions (Fig. 1). The transfer of information from point O1 to point O2 with different coordinate systems is shown in Fig. 2, and without taking into account the directional vector, it is described by a morphological model (matrix and Table 1) with 18 options for implementing the clamping principles (axial, radial, tangential).

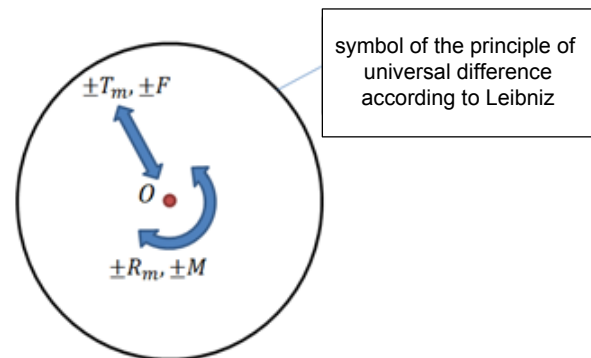


Figure 1. Material point (T.O) is a mechanical gene that carries information about the type of displacements and loads of translational ($\pm T_m$; $\pm F$) and rotational ($\pm R_m$; $\pm M$) with direction indication

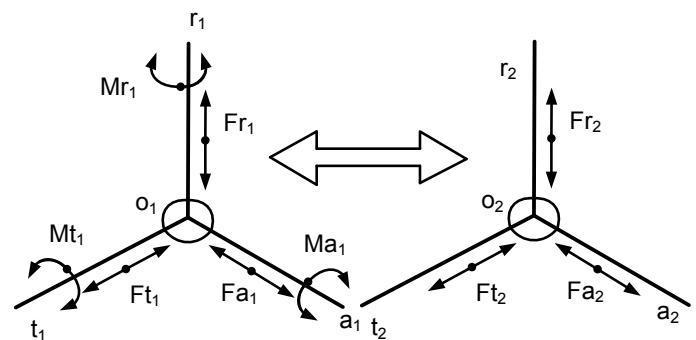


Figure 2. Information transfer from point O1 to point O2

It is suggested to add a tangential principle of a single multi-position clamp having an exerting force on the exit of the system's power flow, to a known genetic classification of single action clamping collet (axial and radial principles with $F_1(M_1) - F_2$) genetic codes). In addition to this realization, the new single multi-

position clamp is also positioned at offset equal to radius R from the rotational axis [12,18]. As a result, the classic genetic code $F_1(M_1) - F_2$ is maintained and a new 24 power flows in addition to the existing 48 genetic classification of power flows will occur (Table 1).

Table 1: Genetic classification of main axial, radial and tangential clamp for axisymmetric rotational workholding device

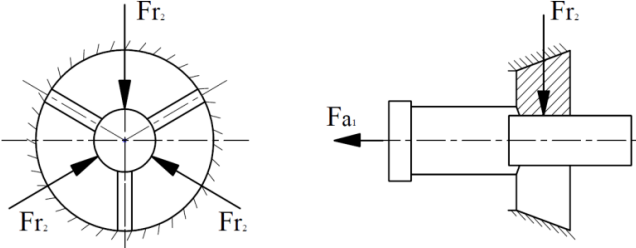
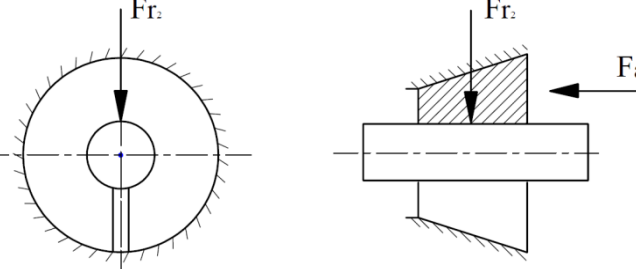
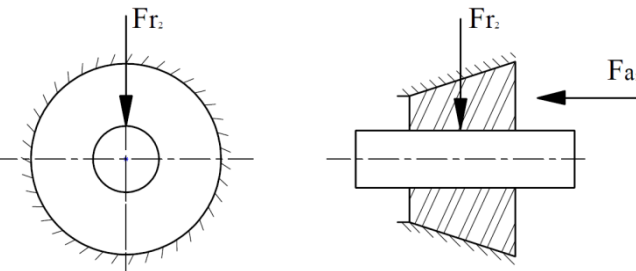
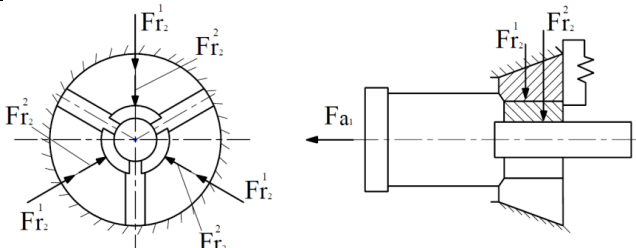
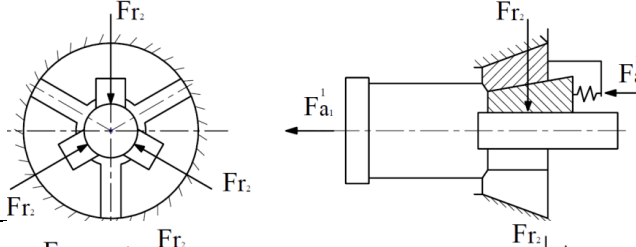
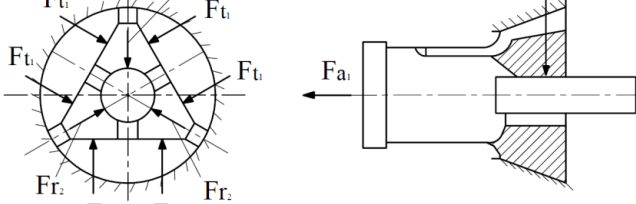
Energy Relationship		Type of force (Moment)	Direction	Output to clamp object Output force F_2					
				Axial force F_{a_2}		Radial Force F_{r_2}		Tangential force F_{t_2}	
Input from energy source	Input force	Axial force F_{a_1}		$F_{a_1}-F_{a_2}$	$F_{a_1}-\underline{F_{a_2}}$	$F_{a_1}-F_{r_2}$	$F_{a_1}-\underline{F_{r_2}}$	$F_{a_1}-F_{t_2}$	$F_{a_1}-\underline{F_{t_2}}$
				$\underline{F_{a_1}}-F_{a_2}$	$\underline{F_{a_1}}-\underline{F_{a_2}}$	$\underline{F_{a_1}}-F_{r_2}$	$\underline{F_{a_1}}-\underline{F_{r_2}}$	$\underline{F_{a_1}}-F_{t_2}$	$\underline{F_{a_1}}-\underline{F_{t_2}}$
		Radial force F_{r_1}		$F_{r_1}-F_{a_2}$	$F_{r_1}-\underline{F_{a_2}}$	$F_{r_1}-F_{r_2}$	$F_{r_1}-\underline{F_{r_2}}$	$F_{r_1}-F_{t_2}$	$F_{r_1}-\underline{F_{t_2}}$
				$\underline{F_{r_1}}-F_{a_2}$	$\underline{F_{r_1}}-\underline{F_{a_2}}$	$\underline{F_{r_1}}-F_{r_2}$	$\underline{F_{r_1}}-\underline{F_{r_2}}$	$\underline{F_{r_1}}-F_{t_2}$	$\underline{F_{r_1}}-\underline{F_{t_2}}$
		Tangential force F_{t_1}		$F_{t_1}-F_{a_2}$	$F_{t_1}-\underline{F_{a_2}}$	$F_{t_1}-F_{r_2}$	$F_{t_1}-\underline{F_{r_2}}$	$F_{t_1}-F_{t_2}$	$F_{t_1}-\underline{F_{t_2}}$
				$\underline{F_{t_1}}-F_{a_2}$	$\underline{F_{t_1}}-\underline{F_{a_2}}$	$\underline{F_{t_1}}-F_{r_2}$	$\underline{F_{t_1}}-\underline{F_{r_2}}$	$\underline{F_{t_1}}-F_{t_2}$	$\underline{F_{t_1}}-\underline{F_{t_2}}$
	Input moment M_1	About rotation axis M_{a_1}		$M_{a_1}-F_{a_2}$	$M_{a_1}-\underline{F_{a_2}}$	$M_{a_1}-F_{r_2}$	$M_{a_1}-\underline{F_{r_2}}$	$M_{a_1}-F_{t_2}$	$M_{a_1}-\underline{F_{t_2}}$
				$\underline{M_{a_1}}-F_{a_2}$	$\underline{M_{a_1}}-\underline{F_{a_2}}$	$\underline{M_{a_1}}-F_{r_2}$	$\underline{M_{a_1}}-\underline{F_{r_2}}$	$\underline{M_{a_1}}-F_{t_2}$	$\underline{M_{a_1}}-\underline{F_{t_2}}$
		About radius M_{r_1}		$M_{r_1}-F_{a_2}$	$M_{r_1}-\underline{F_{a_2}}$	$M_{r_1}-F_{r_2}$	$M_{r_1}-\underline{F_{r_2}}$	$M_{r_1}-F_{t_2}$	$M_{r_1}-\underline{F_{t_2}}$
				$\underline{M_{r_1}}-F_{a_2}$	$\underline{M_{r_1}}-\underline{F_{a_2}}$	$\underline{M_{r_1}}-F_{r_2}$	$\underline{M_{r_1}}-\underline{F_{r_2}}$	$\underline{M_{r_1}}-F_{t_2}$	$\underline{M_{r_1}}-\underline{F_{t_2}}$
		Inplane axis of rotation M_{t_1}		$M_{t_1}-F_{a_2}$	$M_{t_1}-\underline{F_{a_2}}$	$M_{t_1}-F_{r_2}$	$M_{t_1}-\underline{F_{r_2}}$	$M_{t_1}-F_{t_2}$	$M_{t_1}-\underline{F_{t_2}}$
				$\underline{M_{t_1}}-F_{a_2}$	$\underline{M_{t_1}}-\underline{F_{a_2}}$	$\underline{M_{t_1}}-F_{r_2}$	$\underline{M_{t_1}}-\underline{F_{r_2}}$	$\underline{M_{t_1}}-F_{t_2}$	$\underline{M_{t_1}}-\underline{F_{t_2}}$
Clamping principle				Butt		Radial		Tangential	

The structure of the clamping chuck, as a subsystem of a workholding mechanism [9, 10] which realizes a well-defined principal clamping at different levels of difficulty and genetic information can be presented as a group of genetic structural models. During that one should remember

A material point can be fixed, as information about static vehicles of the "object" type (tools, structures, supporting systems of technological equipment), and movable, as information about dynamic vehicles of the "process" type [2, 10]. Thanks to the fruitful cooperation of mechanics and electromechanics using approaches in genetic electromechanics and universal genetic operators of synthesis (replication, inversion, crossing, crossing over, mutation) [13, 22], fundamentally new mechanisms and nodes have been created.

The effectiveness of the proposed approach is clearly illustrated by the example of pull-type collet chucks (CP) with wedge WD and spring SR converters (Table 2), where the force is F_{a1} and F_{t1} at the input, and F_{r2} and F_{t2} at the output. Topology demonstrates the fruitful influence of the contradictions between intuition and logic [12, 16]. Table 2 (pos. 8 and 9) shows examples of the implementation of ideas for creating wide-range collet ZPs with a liquid flowing medium LMF (liquid flowing medium). The same ideas can be implemented for a wide range in shape and size when using bulk media BLM (bulk medium).

Table 2. Schemes of known and new collet chucks with genetic formulas at the population level

№ p/p	Scheme chuck	Genetic formula	Chuck type
1		$F_{a1} - WD - 3F_{r2}$	Standard
2		$F_{a1} - WD - F_{r2}$	High-speed instrumental
3		$F_{a1} - (WD * SR) - F_{r2}$ $WD * SR \rightarrow \text{hybrid GB}$	High-speed tool with spring collet
4		$F_{a1} - WD - 3F_{r2}^1 - SR - 3F_{r2}^2$ or $F_{a1} - (WD * SR) - 3F_{r2}$	High precision with flanged collet
5		$F_{a1}^2 - SR$ $F_{a1}^1 - WD^1 - \otimes$ $- WD^2 - 3F_{r2}$	Self-adjusting
6		$F_{a1} - WD^1 - 3F_{t1}$ $- WD^2 - 3F_{r2}$	Wide-range single multiplication

7		$F_{a1} - WD - 3F_{r2} *$ $* (LMF)$	Wide-range fluidized
8		$F_{a1} - WD - 3F_{t1} *$ $* (LMF) - 3F_{r2}$	Wide-range with tangential clamping and liquid-fluid medium

Below is the implementation of the new approach, formulated by a morphological model in the form of a matrix of clamping principles and as an opening of a folded generating system (Table 1), which is clearly depicted with genetic formulas at the population level (Tables 3 and 4).

Table 3. Examples of the implementation of the principles of clamping in the power flow with the genetic code F_1 - F_2

Nº p/p	Chromosome	Genetic formula at the population level	Principled schema
1	F_{a1} - F_{a2}	F_{a1} -PL- F_{a2}	
2	F_{a1} - F_{r2}	F_{a1} -WD- F_{r2}	
3	F_{a1} - F_{t2}	F_{a1} -WD- F_{t2}	
4	F_{r1} - F_{a2}	F_{r1} -WD- F_{a2}	
5	F_{r1} - F_{r2}	F_{r1} -SR(TRF)- F_{r2}	

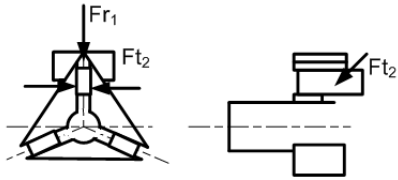
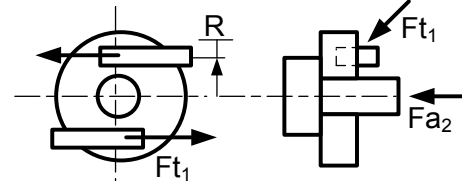
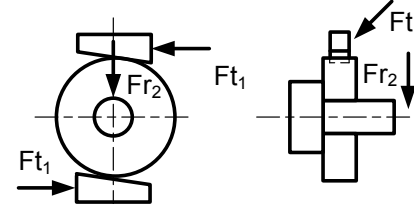
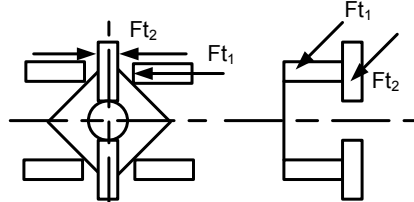
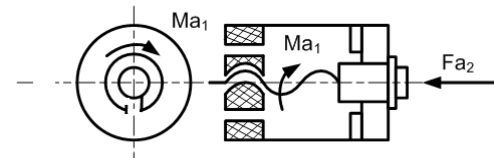
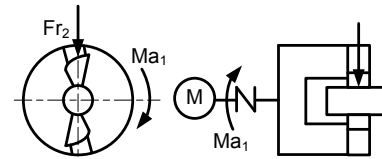
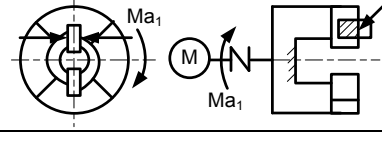
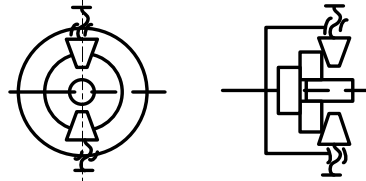
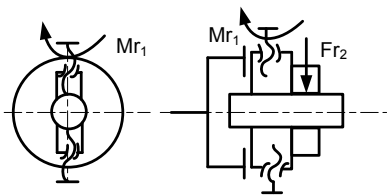
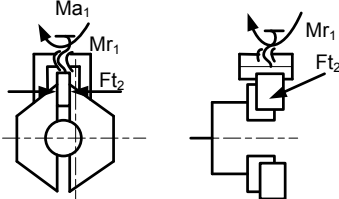
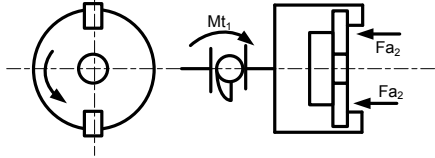
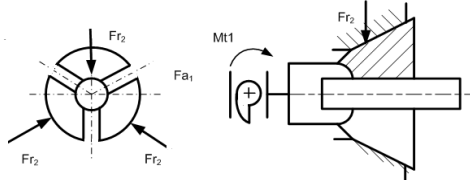
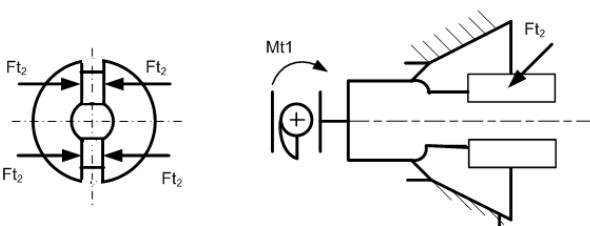
6	Fr_1-Ft_2	$Fr_1-WD-Ft_2$	
7	Ft_1-Fa_2	$Ft_1-WD-Fa_2$	
8	Ft_1-Fr_2	$Ft_1-WD-Fr_2$	
9	Ft_1-Ft_2	$Ft_1-WD-Ft_2$	

Table 4. Examples of the implementation of the principles of clamping in the power flow with the genetic code M_1-F_2

Nº p/p	Chromosome	Genetic formula at the population level	Principled schema
1	Ma_1-Fa_2	$Ma_1-SC(EMF)-Fa_2$	
2	Ma_1-Fr_2	$Ma_1-SP(EMF)-Fr_2$	
3	Ma_1-Ft_2	$Ma_1-SP(EMF)-Ft_2$	
4	Mr_1-Fa_2	$Mr_1-SC-WD-Fa_2$	

5	Mr_1-Fr_2	$Mr_1-SC-Fr_2$	
6	Mr_1-Ft_2	$Mr_1-SC-WD-Ft_2$	
7	Mt_1-Fa_2	$Mt_1-SP-PL-Fa_2$	
8	Mt_1-Fr_2	$Mt_1-SP-WD-Fr_2$	
9	Mt_1-Ft_2	$Mt_1-SP-WD-Ft_2$	

4. Conclusions.

It becomes obvious that Man is not the sole creator of technical progress, as previously thought, but remains only a student of Nature. Everything that has been invented by many generations of specialists has long been foreseen by Nature in its genetic programs. Nature establishes the laws of structural organization, creates genetic programs for the development of complex systems and dictates strict rules for their construction.

The era of transition from virtual to real is coming, since the basis of the progress of material production ("more-better-cheaper") was and remains production technologies and technical means (material and energy flows), and not computers intended for virtual work and related to information streams. They are always only auxiliary and secondary in the TS, but the main ones in intelligent systems. The proposed interdisciplinary approach will allow for an innovative breakthrough and the search for many unexpected non-standard solutions for the creation of new equipment and the latest technologies in a short time in the face of the challenges of Industry 4.0.

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Efficiencies and losses comparison of three steam turbines – from conventional, nuclear and marine power plant

Mrzljak Vedran¹, Prpić-Oršić Jasna¹, Poljak Igor², Baressi Šegota Sandi¹

¹Faculty of Engineering, University of Rijeka, Vukovarska 58, 51000 Rijeka, Croatia

²Department of maritime sciences, University of Zadar, Mihovila Pavlinovića 1, 23000 Zadar, Croatia

E-mail: vedran.mrzljak@riteh.hr, jasna.prpic-orsic@riteh.hr, ipoljak1@unizd.hr, sbaressisegota@riteh.hr

Abstract: This paper presents an analysis and comparison of three steam turbines and its cylinders: from the conventional steam power plant, from nuclear power plant and from the marine propulsion plant. The best parameters for the comparison of whole turbines and its cylinders are: energy loss per unit of produced mechanical power, exergy destruction per unit of produced mechanical power, energy efficiency and exergy efficiency. Steam turbine from marine propulsion plant shows the worst performance, regardless if observing each cylinder or the whole turbine – it has the highest losses per unit of produced mechanical power and the lowest efficiencies (both energy and exergy). Such results can be explained by a fact that marine steam turbine must be much more dynamic in operation in comparison to other two turbines. Also, marine steam turbine analyzed in this paper did not possess steam reheating between the cylinders as the other two observed steam turbines, what has a dominant impact on the obtained results.

KEYWORDS: VARIOUS STEAM TURBINES, EFFICIENCIES, LOSSES, PERFORMANCE COMPARISON

1. Introduction

Steam turbines are nowadays inevitable components of various power plants: conventional [1], nuclear [2], combined [3], cogeneration [4], marine [5] and many others. In the most of the cases, steam turbines are used for electrical generator drive and producing of electrical power [6], but also it can be used for various other purposes in various plants, processes and industries [7, 8].

In the literature can often be found analysis of various power plants inside which are mounted steam turbines as its constituent components [9]. However, a direct comparison of various steam turbines and its cylinders, from various steam power plants is rare.

In order to fulfill a literature gap, in this paper is presented analysis and comparison of three steam turbines and its cylinders: from the conventional steam power plant, from nuclear power plant and from the marine propulsion plant. Parameters selected for direct comparison of observed steam turbines and its cylinders are: energy loss per unit of produced mechanical power, exergy destruction per unit of produced mechanical power, energy efficiency and exergy efficiency.

2. Description of the analyzed steam turbines

In this paper were analyzed three steam turbines along with its cylinders, presented in Fig. 1.

In Fig. 1 (a) is presented scheme of a steam turbine from the conventional steam power plant. HPC has one steam extraction, while the steam mass flow rate which remains after expansion in HPC (operating point 3) is delivered to steam reheater which increases steam temperature. After reheater (operating point 4), steam is delivered to LPC. LPC of this turbine has four steam extractions. After expansion in LPC, remaining steam mass flow rate is delivered to steam condenser [10] for condensation.

Second analyzed steam turbine, from nuclear power plant, is presented in Fig. 1 (b). In comparison to other analyzed steam turbines, this steam turbine dominantly operates with wet steam. HPC of this turbine has two steam extractions. After HPC, it is performed process of steam reheating, which in the case of nuclear power plant consists of moisture separation and reheating [11]. LPC of steam turbine from nuclear power plant has three steam extractions. After LPC, remaining steam mass flow rate is delivered to steam condenser.

Third steam turbine analyzed in this paper is a steam turbine from the marine propulsion plant, presented in Fig. 1 (c). Each cylinder of this turbine (HPC and LPC) has one steam extraction, while the third steam extraction can be noted between two cylinders. In comparison to other analyzed steam turbines, this turbine did not possess steam reheating between cylinders what can be a significant disadvantage. After expansion, steam is delivered to marine steam condenser [12].

First two steam turbines – Fig. 1 (a) and Fig. 1 (b) are used for the Electrical Generator (EG) drive, while marine steam turbine, Fig. 1 (c), drives ship propulsion propeller through the gearbox.

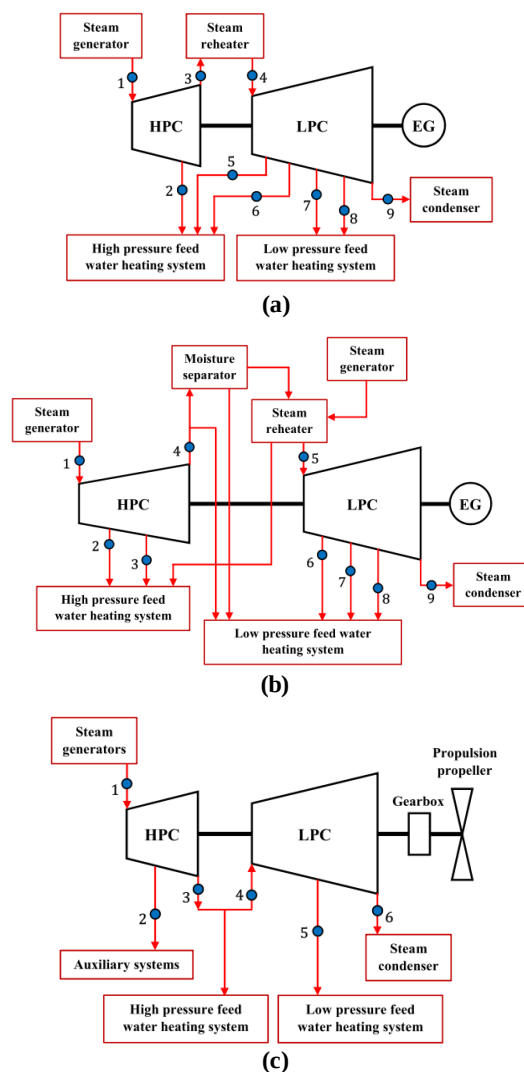


Fig. 1. Observed steam turbines and operating points required for the analysis: (a) From the conventional power plant; (b) From nuclear power plant; (c) From the marine propulsion plant

3. Equations for efficiencies and loss calculation

In this paper will be performed calculation of energy and exergy efficiencies and losses for each cylinder and the whole turbine for all three steam turbines presented in Fig. 1. It should be highlighted that an energy analysis of any system or a control volume did not take into consideration any parameter of the ambient in which system or a control volume operates [13], while exergy analysis takes into consideration parameters of the ambient [14].

3.1. Base energy and exergy balances and principles

The first law of thermodynamics is a baseline for energy analysis, while the second law of thermodynamics is a baseline for exergy analysis [15, 16]. The general energy and exergy balance equations valid for any system or a control volume are [17, 18]:

$$\dot{Q}_{\text{input}} + P_{\text{input}} + \sum \dot{E}n_{\text{input}} = \dot{Q}_{\text{output}} + P_{\text{output}} + \sum \dot{E}n_{\text{output}}, \quad (1)$$

$$\dot{X}_{\text{ex}} + P_{\text{input}} + \sum \dot{E}x_{\text{input}} = P_{\text{output}} + \sum \dot{E}x_{\text{output}} + \dot{E}x_{\text{des}}. \quad (2)$$

In the above equations, P in (kW) is used or produced mechanical power, $\dot{Q}$ in (kW) is the energy transfer by heat, $\dot{X}_{\text{ex}}$ in (kW) is the exergy transfer by heat at the temperature T in (K) and $\dot{E}x_{\text{des}}$ in (kW) is exergy destruction (exergy loss). $\dot{E}n$ in (kW) is a total energy of fluid flow, while $\dot{E}x$ in (kW) is a total exergy of fluid flow. A total energy and exergy of fluid flow are defined as [19, 20]:

$$\dot{E}n = \dot{m} \cdot h, \quad (3)$$

$$\dot{E}x = \dot{m} \cdot \varepsilon. \quad (4)$$

In Eq. (3) and Eq. (4), h in (kJ/kg) is fluid specific enthalpy, ε in (kJ/kg) is fluid specific exergy, while $\dot{m}$ in (kg/s) is the fluid mass flow rate. The overall definition of energy or exergy efficiency is:

$$\eta_{\text{en (ex)}} = \frac{\text{cumulative energy (exergy) output}}{\text{cumulative energy (exergy) input}}. \quad (5)$$

In any system or a control volume during standard operation, fluid mass flow rate leakage did not occur, so the valid mass flow rate balance is [21]:

$$\sum \dot{m}_{\text{input}} = \sum \dot{m}_{\text{output}}. \quad (6)$$

Above presented base equations and principles will be used in the calculation of energy and exergy losses and efficiencies of all turbines from Fig. 1 as well as of each cylinder.

3.2. Energy and exergy efficiencies and losses of the observed steam turbines and cylinders

Equations for the calculation of energy and exergy efficiencies and losses of the whole turbines and each cylinder from Fig. 1 will be presented for steam turbine from the conventional steam power plant (Fig. 1 (a)). For the other observed steam turbines, equations will be defined in accordance to the presented ones. All of the equations are defined according to recommendations from the literature [22-24].

The baseline for the calculation of cylinder or the whole turbine energy losses and energy efficiencies is the comparison of steam expansion process throughout the cylinder or whole turbine. In Fig. 2 is presented comparison of real (polytropic) steam expansion process and ideal (isentropic) steam expansion process between two same pressures. Data of any cylinder or whole turbine real (polytropic) steam expansion process are obtained by measurements inside the power plant. Ideal (isentropic) steam expansion process is obtained mathematically by assuming always the same steam specific entropy during the expansion process, Fig. 2.

In the following equations, operating points for ideal (isentropic) steam expansion will have index IS.

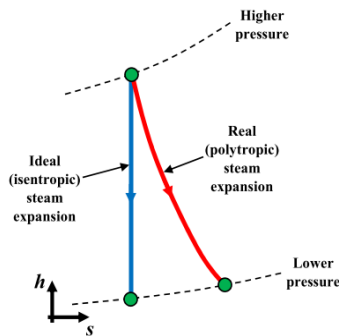


Fig. 2. A comparison of real (polytropic) and ideal (isentropic) steam expansion processes in h-s diagram

All required equations are as follows (operating points numeration is defined in accordance to Fig. 1 (a)):

High Pressure Cylinder (HPC) - conventional steam power plant

- Real (polytropic) mechanical power:

$$P_{\text{RE,HPC}} = \dot{m}_1 \cdot (h_1 - h_2) + (\dot{m}_1 - \dot{m}_2) \cdot (h_2 - h_3). \quad (7)$$

- Ideal (isentropic) mechanical power:

$$P_{\text{ID,HPC}} = \dot{m}_1 \cdot (h_1 - h_{2\text{IS}}) + (\dot{m}_1 - \dot{m}_2) \cdot (h_{2\text{IS}} - h_{3\text{IS}}). \quad (8)$$

- Energy loss:

$$\dot{E}n_{\text{loss,HPC}} = P_{\text{ID,HPC}} - P_{\text{RE,HPC}}. \quad (9)$$

- Energy loss per unit of produced mechanical power:

$$\dot{E}n_{\text{loss,HPC,kW}} = \frac{\dot{E}n_{\text{loss,HPC}}}{P_{\text{RE,HPC}}} \cdot 100. \quad (10)$$

- Energy efficiency:

$$\eta_{\text{en,HPC}} = \frac{P_{\text{RE,HPC}}}{P_{\text{ID,HPC}}} \cdot 100. \quad (11)$$

- Exergy destruction (exergy loss):

$$\dot{E}x_{\text{des,HPC}} = \dot{E}x_1 - \dot{E}x_2 - \dot{E}x_3 - P_{\text{RE,HPC}}. \quad (12)$$

- Exergy destruction per unit of produced mechanical power:

$$\dot{E}x_{\text{des,HPC,kW}} = \frac{\dot{E}x_{\text{des,HPC}}}{P_{\text{RE,HPC}}} \cdot 100. \quad (13)$$

- Exergy efficiency:

$$\eta_{\text{ex,HPC}} = \frac{P_{\text{RE,HPC}}}{\dot{E}x_1 - \dot{E}x_2 - \dot{E}x_3} \cdot 100. \quad (14)$$

Low Pressure Cylinder (LPC) - conventional steam power plant

- Real (polytropic) mechanical power:

$$P_{\text{RE,LPC}} = \dot{m}_4 \cdot (h_4 - h_5) + (\dot{m}_4 - \dot{m}_5) \cdot (h_5 - h_6) + (\dot{m}_4 - \dot{m}_5 - \dot{m}_6) \cdot (h_6 - h_7) + (\dot{m}_4 - \dot{m}_5 - \dot{m}_6 - \dot{m}_7) \cdot (h_7 - h_8) + \dot{m}_9 \cdot (h_8 - h_9). \quad (15)$$

- Ideal (isentropic) mechanical power:

$$P_{\text{ID,LPC}} = \dot{m}_4 \cdot (h_4 - h_{5\text{IS}}) + (\dot{m}_4 - \dot{m}_5) \cdot (h_{5\text{IS}} - h_{6\text{IS}}) + (\dot{m}_4 - \dot{m}_5 - \dot{m}_6) \cdot (h_{6\text{IS}} - h_{7\text{IS}}) + (\dot{m}_4 - \dot{m}_5 - \dot{m}_6 - \dot{m}_7) \cdot (h_{7\text{IS}} - h_{8\text{IS}}) + \dot{m}_9 \cdot (h_{8\text{IS}} - h_{9\text{IS}}). \quad (16)$$

- Energy loss:

$$\dot{E}n_{\text{loss,LPC}} = P_{\text{ID,LPC}} - P_{\text{RE,LPC}}. \quad (17)$$

- Energy loss per unit of produced mechanical power:

$$\dot{E}n_{\text{loss,LPC,kW}} = \frac{\dot{E}n_{\text{loss,LPC}}}{P_{\text{RE,LPC}}} \cdot 100. \quad (18)$$

- Energy efficiency:

$$\eta_{\text{en,LPC}} = \frac{P_{\text{RE,LPC}}}{P_{\text{ID,LPC}}} \cdot 100. \quad (19)$$

- Exergy destruction (exergy loss):

$$\dot{E}x_{\text{des,LPC}} = \dot{E}x_4 - \dot{E}x_5 - \dot{E}x_6 - \dot{E}x_7 - \dot{E}x_8 - \dot{E}x_9 - P_{\text{RE,LPC}}. \quad (20)$$

- Exergy destruction per unit of produced mechanical power:

$$\dot{E}x_{\text{des,LPC,kW}} = \frac{\dot{E}x_{\text{des,LPC}}}{P_{\text{RE,LPC}}} \cdot 100. \quad (21)$$

- Exergy efficiency:

$$\eta_{\text{ex,LPC}} = \frac{P_{\text{RE,LPC}}}{\dot{E}x_4 - \dot{E}x_5 - \dot{E}x_6 - \dot{E}x_7 - \dot{E}x_8 - \dot{E}x_9} \cdot 100. \quad (22)$$

Whole Turbine (WT) - conventional steam power plant

- Real (polytropic) mechanical power:

$$P_{\text{RE,WT}} = P_{\text{RE,HPC}} + P_{\text{RE,LPC}}. \quad (23)$$

- Ideal (isentropic) mechanical power:

$$P_{ID,WT} = P_{ID,HPC} + P_{ID,LPC} \quad (24)$$

- Energy loss:

$$\dot{E}n_{loss,WT} = P_{ID,WT} - P_{RE,WT} \quad (25)$$

- Energy loss per unit of produced mechanical power:

$$\dot{E}n_{loss,WT,kW} = \frac{\dot{E}n_{loss,WT}}{P_{RE,WT}} \cdot 100. \quad (26)$$

- Energy efficiency:

$$\eta_{en,WT} = \frac{P_{RE,WT}}{P_{ID,WT}} \cdot 100. \quad (27)$$

- Exergy destruction (exergy loss):

$$\dot{E}x_{des,WT} = \dot{E}x_1 - \dot{E}x_2 - \dot{E}x_3 + \dot{E}x_4 - \dot{E}x_5 - \dot{E}x_6 - \dot{E}x_7 - \dot{E}x_8 - \dot{E}x_9 - P_{RE,WT} \quad (28)$$

- Exergy destruction per unit of produced mechanical power:

$$\dot{E}x_{des,WT,kW} = \frac{\dot{E}x_{des,WT}}{P_{RE,WT}} \cdot 100. \quad (29)$$

- Exergy efficiency:

$$\eta_{ex,WT} = \frac{P_{RE,WT}}{\dot{E}x_1 - \dot{E}x_2 - \dot{E}x_3 + \dot{E}x_4 - \dot{E}x_5 - \dot{E}x_6 - \dot{E}x_7 - \dot{E}x_8 - \dot{E}x_9} \cdot 100. \quad (30)$$

4. Steam operating parameters for each turbine

Table 1. Steam operating parameters of the turbine from the conventional power plant [25]

O.P.*	Steam mass flow rate (kg/s)	Steam temperature (°C)	Steam pressure (bar)	Steam quality
1	119.25	556.45	148.96	Superheated
2	15.51	370.00	38.90	Superheated
3	103.74	362.78	36.67	Superheated
4	103.74	512.17	35.80	Superheated
5	6.97	480.53	23.53	Superheated
6	6.86	360.00	10.50	Superheated
7	7.12	248.20	2.50	Superheated
8	4.87	160.00	1.10	Superheated
9	77.92	42.94	0.08625	0.94

* O.P. = Operating point; in accordance with Fig. 1. (a)

Table 2. Steam operating parameters of turbine from nuclear power plant [26]

O.P.*	Steam mass flow rate (kg/s)	Steam temperature (°C)	Steam pressure (bar)	Steam quality
1	1543.58	274.63	59.130	0.994
2	129.95	225.11	25.550	0.925
3	64.63	185.280	11.306	0.885
4	1349.00	163.33	6.724	0.865
5	1057.27	240.60	6.650	Superheated
6	46.72	128.19	1.961	Superheated
7	43.55	93.72	0.807	0.964
8	45.73	73.32	0.360	0.931
9	921.27	40.63	0.076	0.898

* O.P. = Operating point; in accordance with Fig. 1. (b)

Table 3. Steam operating parameters of turbine from marine propulsion plant [27]

O.P.*	Steam mass flow rate (kg/s)	Steam temperature (°C)	Steam pressure (bar)	Steam quality
1	26.798	500.00	58.99	Superheated
2	0.908	350.00	15.65	Superheated
3	25.891	256.00	5.93	Superheated
4	22.110	256.00	5.93	Superheated
5	0.932	153.00	1.21	Superheated
6	21.178	34.94	0.0561	92.100

* O.P. = Operating point; in accordance with Fig. 1. (c)

Steam operating parameters (temperature, pressure, steam quality and mass flow rate) in each operating point of each observed turbine from Fig. 1 are presented in Table 1 for turbine from the conventional power plant, in Table 2 for turbine from nuclear power plant and in Table 3 for turbine from the marine propulsion plant. Other steam operating parameters are calculated by using NIST REFPROP 9.0 software [28]. In this analysis, the base ambient state is defined by the ambient pressure of 1 bar and the ambient temperature of 25 °C.

5. Results and discussion

In comparison to turbines from conventional and nuclear power plant, the highest energy loss per unit of produced mechanical power has steam turbine from the marine propulsion plant (conventional = 20.74%, nuclear = 23.24% and marine = 31.02%), Fig. 3. When observing the whole turbines, turbine from the conventional steam power plant has the highest energy efficiency (82.82%), followed by turbine from nuclear power plant (81.14%), while the lowest energy efficiency has a turbine from marine propulsion plant (76.33%).

Obtained results can be explained by a fact that marine steam turbine must be much more dynamic in operation in comparison to other two turbines. Also, marine steam turbine did not possess steam reheating between the cylinders – a newer version of marine steam turbines have three cylinders with steam reheating between HPC and IPC (Intermediate Pressure Cylinder) [29].

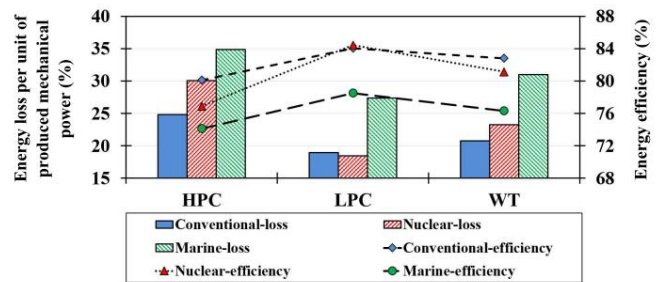


Fig. 3. Energy analysis parameters of three observed steam turbines and its cylinders

Exergy destruction per unit of produced mechanical power for the whole turbines is equal to 15.18% for turbine from the conventional steam power plant, 18.62% for turbine from nuclear power plant and 23.78% for the turbine from the marine propulsion plant, Fig. 4.

Turbine from the conventional steam power plant has the highest exergy efficiency (86.82%), followed by turbine from nuclear power plant (84.30%), while the lowest exergy efficiency has a turbine from marine propulsion plant (80.79%).

As in comparison of energy analysis parameters, Fig. 3, comparable exergy analysis parameters of all turbines and its cylinders, Fig. 4, show again that the steam turbine from the marine propulsion plant has the worst performance.

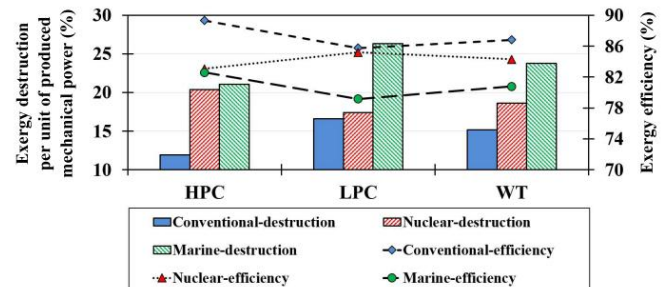


Fig. 4. Exergy analysis parameters of three observed steam turbines and its cylinders

Further analyses will be performed by using various artificial intelligence methods [30-33].

6. Conclusions

In this paper is performed analysis and comparison of three steam turbines and its cylinders: from the conventional steam power plant, from nuclear power plant and from the marine propulsion plant. The most important conclusions of the performed analysis are:

- Comparison of the whole turbines show that the lowest energy loss per unit of produced mechanical power has steam turbine from the conventional steam power plant (20.74%), followed by steam turbine from nuclear power plant (23.24%), while the highest energy loss per unit of produced mechanical power has steam turbine from the marine propulsion plant (31.02%). Exergy destruction per unit of produced mechanical power for the whole turbines is equal to 15.18% for turbine from the conventional steam power plant, 18.62% for turbine from nuclear power plant and 23.78% for the turbine from the marine propulsion plant.
- Turbine from the conventional steam power plant has the highest energy efficiency (82.82%), followed by turbine from nuclear power plant (81.14%), while the lowest energy efficiency has a turbine from marine propulsion plant (76.33%). Also, turbine from the conventional steam power plant has the highest exergy efficiency (86.82%), followed by turbine from nuclear power plant (84.30%), and turbine from marine propulsion plant (80.79%).
- The worst performance shows steam turbine from the marine propulsion plant because it did not possess steam reheating between the cylinders as the other two observed steam turbines.

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Analysis of sinking of GRP pipe string DN 1600

Klodian Gumeni¹, Koço Bode² Klodian Dhoska²
Polytechnic University of Tirana, Albania
Email: klodigumeni68@gmail.com

Abstract: The aim of this research it was the installation of a discharge sea water pipeline DN 1600 of GRP (glass-reinforced plastic) material in Vlore Bay. The analysis of the sinking of the pipe string has been carried out by using CAESAR II software and considering different load cases. The calculation was carried out for static condition (sustained load) and transient condition (occasional load). In consideration were taken the allowable stress due to bending for pipe and allowable stress for joint subjected to freezing. From the calculation it was evident that the most critical effect on the GRP pipe has done by the position of Concentrated Force due to the presence of sledge (approx. 2 tons), not disassembled from the string after moving in the position from the shore. In these cases, where the central crane has been maintained fixed or moved downward, the maximum bending stress on the pipe was 12.03 MPa. According to the verification carried out for pipe wall in the transient condition (occasional load) the stability was good and for the joint, was shown, in the worst scenario, a bending stress 158% of the allowable one. In this case it is possible to have the crack of the resin used for the freezing of the joint but not the failure of the system joint + pipe that can withstand without, failure, a stress 3 times greater than the allowable stress for pipe according to EN1796.

KEY-WORDS: COMPOSITE MATERIAL, PIPE STRING, ALLOWABLE STRESS, INFLECTION TEST.

1. Introduction

The Cooling Water System is one of the components of the Combined Cycle Generating Power Plant that is constructed in the bay of Vlore. Its scope is to provide the Plant with the required quantity of water for the necessity of cooling circuit of the engines and to return to sea, after use, the warm water.

For this reason was carried out the installation of the submarine pipelines deputed to the carriage of the water from the open sea to the plant and to their discharge.

The pipelines installed there are hereby listed:

- 1800 mm I.D., approx 1455 m long GFR Water Intake pipeline
- 1600 mm I.D., approx 1050 m long GFR Outfall Water Discharging pipeline
- 90 mm I.D., approx 1475 m long High Density Polyethylene Chlorination line.

Glass Fiber Reinforced (GFR) pipes were used for the lightness, handiness, corrosion resistance and versatility that this material is supplying, together with the reliability of the bell & spigot pipe joint system that is ensuring a high quality sealing and a high resistance to the axial forces.

For safety the two pipelines have been considered to be buried in a way that, when completely installed, their top was protected by a minimum cover of 1,5 m of soil. The trench was of sufficient dimensions to accommodate the pipelines and had appropriate slopes to prevent the surrounding material to fall into the excavation during pipeline installation.

The two lines were laid in the same trench from the connection points onshore till the Outfall point (approx. 645 m far from the shoreline); afterwards the trench have accommodated only the 1.800 mm I.D. line till the Intake structure.

The two pipelines were laid on a 30 cm layer of bedding material, to prevent damages deriving from possible idle bumps against rock or stones and to provide smoothed alignment within the allowable piping profile.

At the end of the laying of the two pipelines the trench was backfilled with the aforesaid minimum cover of material.

The same trenched configuration is foreseen on the land, from the shoreline to the connection with the plant structure.

The bell & spigot pipe joint is shown in the figure 1. There are shown the two O ring gaskets which ensure a high quality sealing and the locking device which ensure a high resistance to the axial forces.

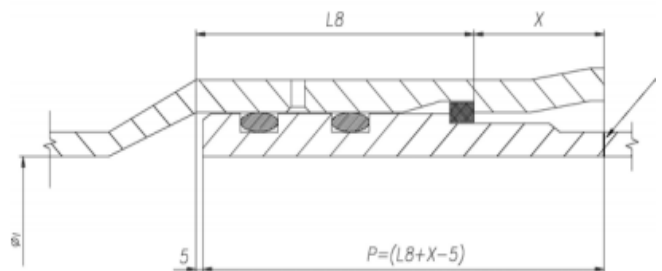


Figure 1. The bell & spigot joint

The methodology of the joint installation is shown in the figure 2, where is very important the alignment of the two pipes.

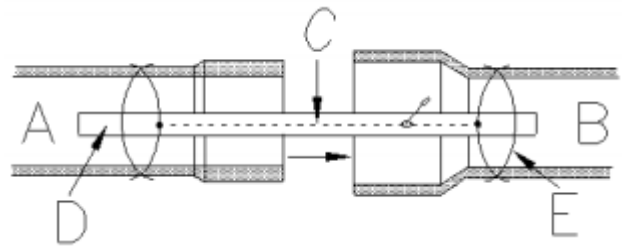


Figure 2. The methodology of the joint installation

- A - Pipe being installed
- B - Installed pipe
- C - Tirfor, one on each side
- D - Plank on both sides to prevent pipe damage.
- E - Nylon or rope

The prefabricated GFR pipes were 12 m long and the installation of the pipelines were carried out one by one by the specialized divers. After the pipelines installation, during the commissioning of the cooling water system was realized that the water didn't came in the Power Plant. After these were carried out some surveys either with divers and ROV (remote operated vehicle), which was put in the pipeline from the water intake and from the diffuser. Was found that both the lines (intake and discharge) were opened at least in one point and had nonconformities in a part of their lengths.

These break points were found uncovered, without the backfilling material and so no protected from the wave action and currents.

After this a root cause analysis was carried out and was decided to make a hydraulic design review and after this to fit a proper installation methodology.

2. Root cause analysis

The first inspection was carried out with divers in the point where the water intake pipeline was broken. It was a sequence of events that leads to the failure of the pipe. These events are summarized as follows:

- Misalignment and successive displacement of the piping joint in the suction line (with failure of one connection)
- Further to continuous suction of SWMP (for several days during the commissioning activities), the displacement of this joint caused the partial uncovering of the surrounding areas of the pipeline.
- Some of the fill around the pipe was consequently drawn into the pipe leaving a void.
- Finally, the very rough and adverse sea conditions caused the displacement of the joint that, consequently, was no buried anymore.

The reason of the failure was the defective installation of the offshore pipelines. Anyway was decided to make deeper surveys in all the lengths of the pipeline and was found that both the pipes were broken and disconnected from the pipe strings with several displacements and these sections were filled with sediments, etc. The results of the survey are shown in the figure 3.

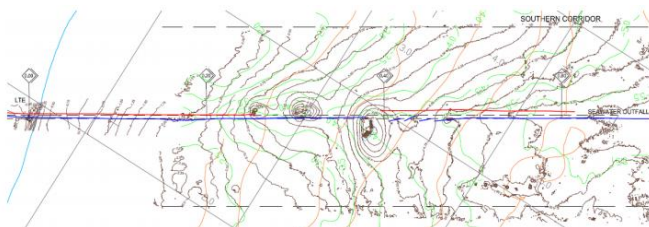


Figure 3. Detail plan view of damaged CW lines

These results have shown that a length of 380 m of the intake pipeline and a length of 370 m of the outfall pipeline should be replaced. In order to be successfully was decided to make a hydraulic design review and to find a proper method for pipe installation.

To avoid the joint of the pipes offshore, was decided to prefabricated long strings (approximately 100 m) onshore and then to transport and laid them on the offshore trench. To put such heavy pipeline in a shallow sea shore it was an engineering challenge and it was not easy to find the proper methodology for the pipeline installation.

Here below we will show the analysis of sinking of pipe string and the methodology used to lay such strings in the trench.

3. Hydraulic design review

In the hydraulic design review were included:

1. Hydrodynamic condition
Waves, water levels, currents, temperature [1]
2. Seabed stability
Bed mobility, seasonal changes, scour [2]
3. Sediment suspension
Concentration profile, ingress rate [3]
4. Pipe hydrodynamics
Hydraulic gradient, sediment transporting capacity [4]
5. Temperature dispersion near the diffuser [5]
6. Sea state analysis
7. In service bottom stability

The results taken from the hydraulic design are shown here below:



Figure 4. Computer model of wave conditions, at SMB, intake and pipelines routes.

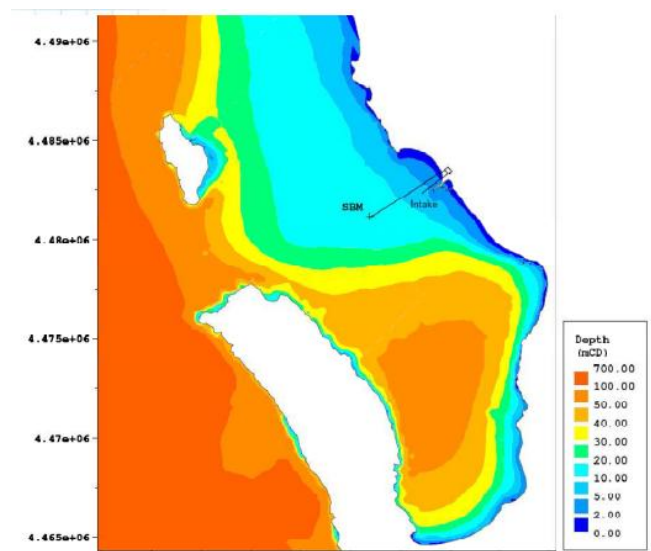


Figure 5. Bathymetry on gridded model "SWAN"

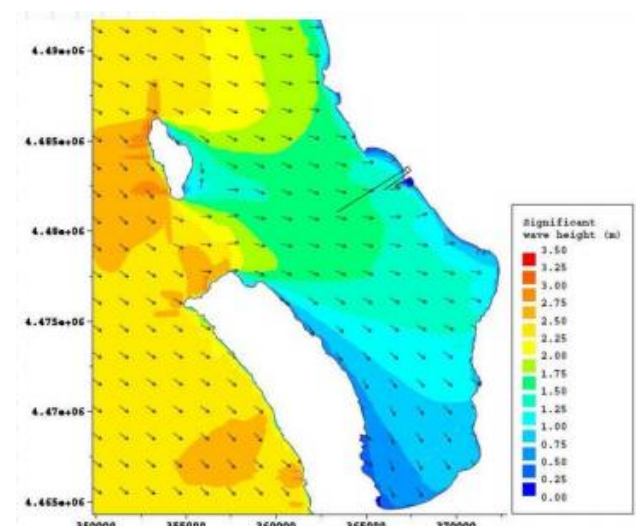


Figure 6. Transformation of offshore waves and swell plus locally-generated waves

Return period (years)	Offshore wave condition				Wave condition at Intake			
	Wave direction (°N)	Significant wave height (m)	Mean wave period (s)	Peak wave period (s)	Significant wave height (m)	Mean wave period (s)	Peak wave period (s)	Wave direction (°N)
1	220	3.5	6.9	8.5	1.5	3.7	8.7	235
	250	2.4	5.8	7.1	1.6	4.2	7.1	243
	270	2.1	5.4	6.7	1.4	3.9	6.4	251
	290	2.5	6.0	7.4	1.7	4.4	7.1	258
	320	2.7	6.3	7.7	1.6	4.1	7.9	276
	360	2.6	6.0	7.4	1.2	3.1	7.1	291
10	220	4.5	7.9	9.7	2.0	4.5	9.7	235
	250	3.6	7.0	8.6	2.5	5.2	8.7	241
	270	3.2	6.7	8.2	2.3	5.2	7.9	246
	290	3.6	7.2	8.9	2.5	5.5	8.7	251
	320	3.7	7.3	9	2.3	5.0	8.7	270
	350	3.5	7.0	8.6	1.8	4.2	8.7	284
100	220	5.6	8.7	10.7	2.4	5.0	10.7	235
	250	4.7	8.0	9.9	2.9	5.8	9.7	240
	270	4.2	7.6	9.4	2.9	5.8	9.7	243
	290	4.8	8.3	10.2	2.9	6.3	10.7	247
	320	4.7	8.2	10.1	2.7	5.6	10.7	264
	350	4.3	7.9	9.7	2.3	4.7	9.7	280

Table 1. Offshore and inshore extreme waves and climate

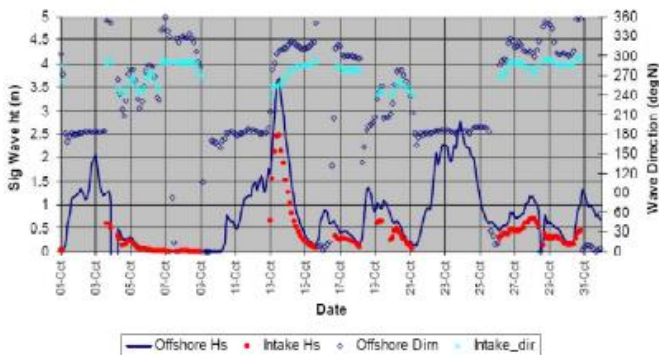


Figure 7. Offshore and inshore construction storms for one month

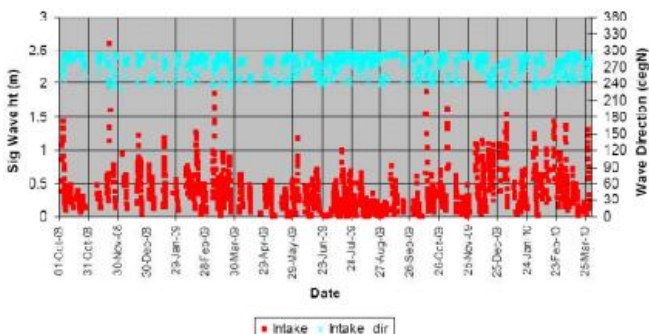


Figure 8. Offshore and inshore construction storms for two years

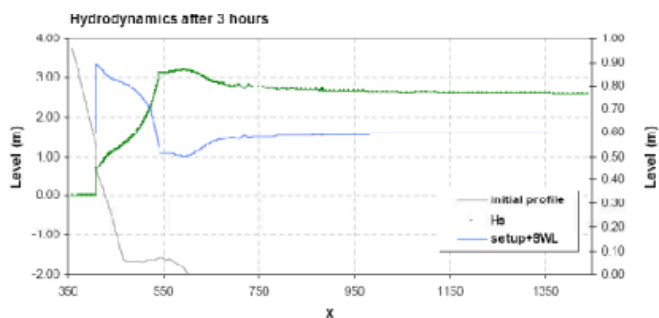


Figure 9. Waves in the surf zone

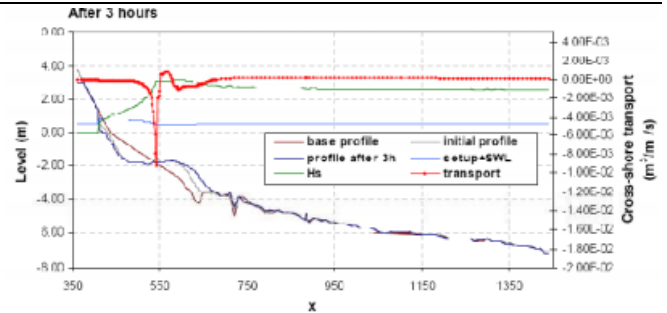


Figure 10. Bed mobility in the surf zone

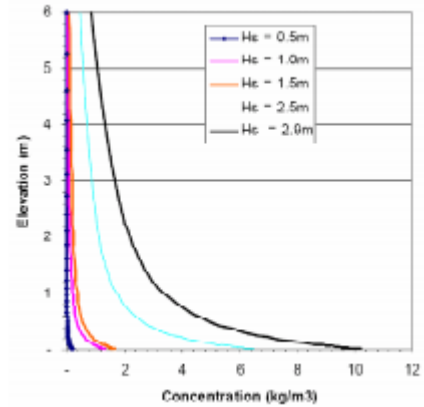


Figure 11. Sediment suspension by waves of different sizes

Test	Frequency	H_s (m)	T_p (s)	V_s (m/s)	C_m (kg/m³)	Ingress (kg/s)	Ingress (tonne/h)
1	50 d/y	0.5	8.7	0.1	0.01	0.03	0.07
2	11 d/y	1.0	8.7	0.1	0.12	0.4	1.5
3	3 d/y	1.5	8.7	0.1	0.24	0.8	3
4	1:10 y	2.5	8.7	0.1	1.15	3.8	14
5	1:100 y	2.9	10.7	0.1	2.23	7.4	27

Table 2. Sediment suspension by waves of different sizes

Sand depth (m)	0.018		0.036		0.09		0.18		0.45	
	C_v kg/s	i m/km	C_v kg/s	i m/km	C_v kg/s	i m/km	C_v kg/s	i m/km	C_v kg/s	i m/km
0.2mm sand										
Clean	2.0	0.75	2.3	0.8	3.4	1.1	5.8	1.4	18	2.4
Aged	3.0	1.2	3.4	1.3	4.6	1.5	7.3	1.8	21	2.9
0.1mm sand										
Clean	10	0.7	13	0.8	21	0.9	38	1.2	168	2.2
Aged	23	1.1	27	1.2	37	1.4	62	1.6	232	2.7

Table 3. Transporting capacity of the pipe.

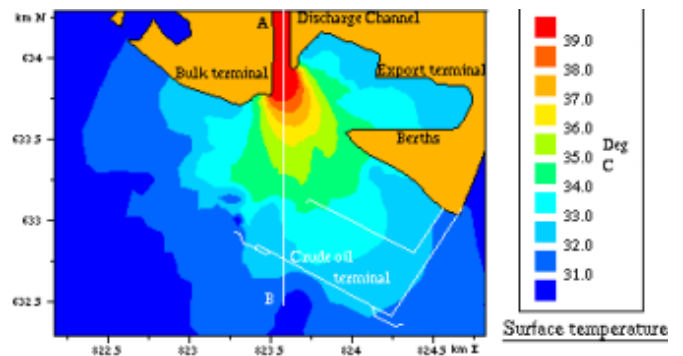


Figure 12. Surface temperature patterns

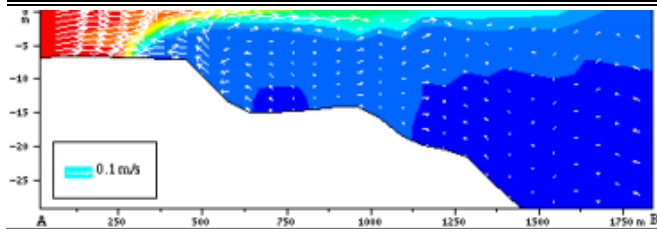


Figure 13. Vertical section of temperature and flow patterns

3.1 Sea state analysis

3.1.1 Bathymetry and oceanographic input data

The following input data are taken in consideration:

- Current velocity in all direction can be estimated as 0,5 m/sec.
- Significant wave height, corresponding to the position of the water outlet, with a return period of 100 years = 2,5 m.
- Wave period = 6 sec and 11 sec.

The stability analysis is based on a return period of 100 year of near-bottom environmental conditions acting on the pipe. Both near bottom wave induced particle velocities and near bottom current induced particle velocities are considered. The effect of the wave has been analyzed by means of the software SACS (Structural Analysis Computer System-Engineering Dynamics, Inc.) and then considering that the waves act on a direction of about 45 ° from the pipe longitudinal axis. From the safe side, current velocity has been assumed acting in orthogonal direction to the pipe longitudinal axis with value of 0,5 m/sec nearby the water surface [6]. Reduction due to seabed interference is evaluated according to VERITEC RP E305 Code [7].

3.1.2 Sea state results – waves

The velocity and acceleration, during the waves development, i.e. considering various waves position and particles depth, were calculated for wave periods $T=6$ sec and $T=11$ sec.

Should be mentioned that U_s and A_s are modified by a directional correction factor (= $\sin \alpha$ where α is the direction angle of wave referred to pipeline axis; $\alpha = 45^\circ$) [8].

3.1.3 Sea state results – currents

To calculate average velocity across the pipeline at the seabed, the following formula (VERITEC RP E305 Code) was applied.

$$\frac{U_D}{U_r} = \frac{1}{\ln\left(\frac{Z_r}{Z_0} + 1\right)} \left\{ \left[1 + \frac{Z_0}{D} \right] \ln\left(\frac{D}{Z_0} + 1\right) - 1 \right\}$$

With the assumption of:

$Z_r = 5$ m above seabed

$U_r = 0,5$ m/sec at el. Z_r

Z_0 is depending on the grain size of the seabed soil.

For the specific case, i.e. gravel-cobble bed material (after seabed preparation):

$d_{50} = 50$ mm (grain size)

$Z_0 = 4,17 \times 10^{-3}$ m (roughness).

With $D = 0,8$ and $0,6$ m (only equivalent approx.. to half outer diameter, in reason of partial embedment), substituting in the equation:

Pipe 1600 mm:

$$\frac{U_D}{U_r} = 0,60$$

$$\frac{U_D}{U_r} = 0,5 \times 0,6 = 0,3 \text{ m/sec}$$

Pipe 1150 mm:

$$\frac{U_D}{U_r} = 0,55$$

$$\frac{U_D}{U_r} = 0,5 \times 0,55 = 0,275 \text{ m/sec}$$

3.2 In service bottom stability for outfall line

The “in-service bottom stability” calculation was carried out according to VERITEC RP E305 Code (1988) “On bottom stability design of submarine pipes”, simplified stability analysis method.

The method gives pipes weights that form a conservative envelope of those obtained from a generalized stability analysis. This method may be used for the stability calculation where the required submerged weight is the only parameter of interest, as in our case.

The stability is given by the following expression:

$$\left(\frac{W_s}{F_w} - F_L \right) \mu \geq F_D + F_t$$

Where:

W_s = submerged weight of the pipe

F_w = calibration factor

μ = soil friction = 0,7 (sandy soil)

F_L = lift force

F_D = drag force

F_t = inertia force

And therefore, the limiting value of submerged weight can be found from:

$$W_s \geq R$$

Ku:

$$R = \left(\frac{(F_D + F_t) + \mu F_L}{\mu} \right) F_w$$

$$F_L = \frac{\gamma}{2g} D C_L (U_s + U_D)^2$$

$$F_D = \frac{\gamma}{2g} D C_D (U_s + U_D)(U_s + U_D)$$

$$F_t = \frac{\pi D^2 \gamma}{4g} C_M A_s$$

Where:

$C_L = 0,9$ (lift force coefficient)

$C_D = 0,7$ (drag force coefficient)

$C_M = 3,29$ (inertia force coefficient)

A_s = significant acceleration perpendicular to the pipeline at each phase

U_D = Current velocity perpendicular to the pipeline

U_s = significant near bottom wave velocity perpendicular to the pipeline

D = pipeline diameter

The relationship between F_w (calibration factor) and K and M is shown in figure 14.

$$K = \frac{U_s T_U}{D} \text{ (Keulegan – Carpenter number)}$$

$$M = \frac{U_D}{U_s}$$

Where:

T_U = mean up-zero crossing period.

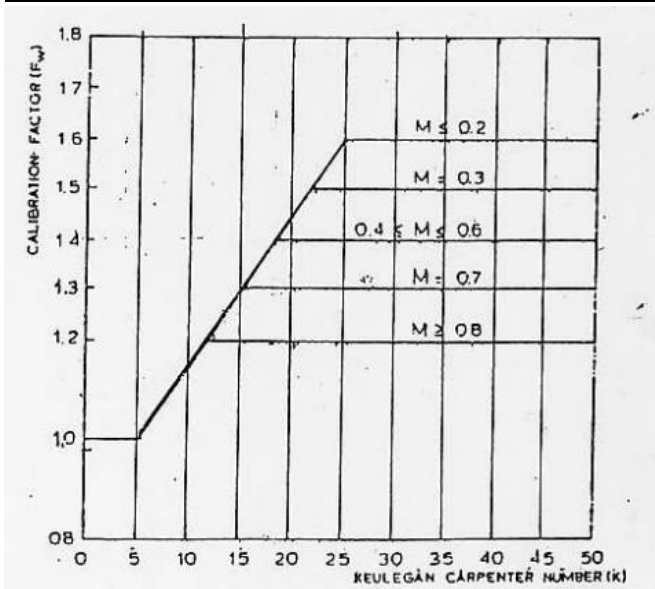


Figure 14. The relationship between F_w and Keulegan-Carpenter number

The results for the bottom stability for $D = 1600$ mm and $T = 6$ sec are shown in the table 4. The other results are not shown here due to the space that they occupy.

All the results for the bottom stability were ok and the stability of the outfall pipe was ensured.

PHASE	(°)	0	20	40	60	80	100	120	140	160	180
U_s	(m/s)	1,35	1,23	0,91	0,47	0,02	0,36	0,65	0,84	0,95	0,98
U_b	(m/s)	0,95	0,87	0,64	0,33	0,01	0,25	0,46	0,59	0,67	0,69
A_s	(m/s ²)	0	0,58	1,05	1,29	1,28	1,07	0,78	0,49	0,24	0
A_b	(m/s ²)	0,00	0,41	0,74	0,91	0,91	0,76	0,55	0,35	0,17	0,00
U_d	(m/s)	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3
F_i	(kg/m)	60	52	34	15	4	12	22	30	36	37
F_d	(kg/m)	46	40	26	12	3	9	17	24	28	29
F_t	(kg/m)	0	71	129	158	157	131	96	60	29	0
K		7	7	5	2	0	2	3	4	5	5
M		0,3	0,3	0,5	0,9	21,2	1,2	0,7	0,5	0,4	0,4
F_w		1,1	1,1	1	1	1	1	1	1	1	1
R	(kg/m)	138	232	255	258	232	212	183	150	117	79
$W_s > R$		ok	ok	ok	ok	ok	ok	ok	ok	ok	ok

Table 4. The results for $D = 1600$ mm and $T = 6$ sec.

4. Analysis of sinking of pipe string DN 1600

The analysis of the sinking of the pipe string has been carried out by using CAESAR II software and considering different load cases.



Figure 15. Floating of the pipe string DN 1600

The scheme of lifting points is indicated in the figure 16, where: $L = 115$ m, $L_1 = 15$ m and $L_2 = 42,5$ m.

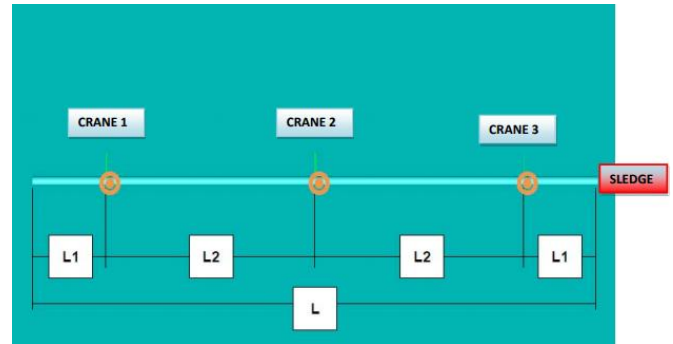


Figure 16. Scheme of lifting points

On the left side of the string has been maintained installed during the operation a carbon steel sledge, used for towing with the weight of approximately 2 tons. This equipment was considered as a concentrated force.

The main nodes of the system are indicated below:

- Crane – 1: Node no. 34
- Crane – 2: Node no. 102
- Crane – 3: Node no. 170
- Sledge (concentrated force): Node no. 230

The following allowable stress was verified in the calculation:

Static condition (sustained load).

- Allowable stress due to bending for pipe: 9,88 MPa.
- Allowable stress for Joint subjected to freezing: 6,26 MPa.

Transient condition (occasional load)

- Allowable stress due to bending for pipe: $9,88 \times 1,5 = 14,82$ MPa
- Allowable stress for Joint subjected to freezing $6,26 \times 1,5 = 9,39$ MPa.

Should be noted that with the string prefabrication onshore, the joints between pipes became stiff, losing their flexibility for angular movements, due to reason of the transport and installation.

The calculation has been carried out considering six calculation schemes. Here we will show the calculation only for the scheme no.1, but obviously the calculation were carried out for all six schemes and the results will be reported here below.

Calculation no. 1.

LOAD CASE	DISPLACEMENTS	VERTICAL MOVEMENTS		
		CRANE 1 (mm)	CRANE 2 (mm)	CRANE 3 (mm)
LC 1	D1	-500	0	500
LC 2	D2	-500	0	750
LC 3	D3	-500	0	1000
LC 4	D4	-500	0	1250
LC 5	D5	-500	0	1500

Table 5. Scheme of calculation no. 1

For calculation no. 1, we have obtained the following maximum stress for different load cases:

LOAD CASE	DISPLACEMENTS	MAXIMUM STRESS (MPa)	NODE
LC 1	D1	12.03	170
LC 2	D2	12.03	170
LC 3	D3	12.03	170
LC 4	D4	12.03	170
LC 5	D5	12.03	170

Table 6. Maximum bending stress for calculation no. 1

The maximum stress and deflection were found for all five load cases; LC1 to LC5, but here, due to space reason, we will show just for the load case LC1.

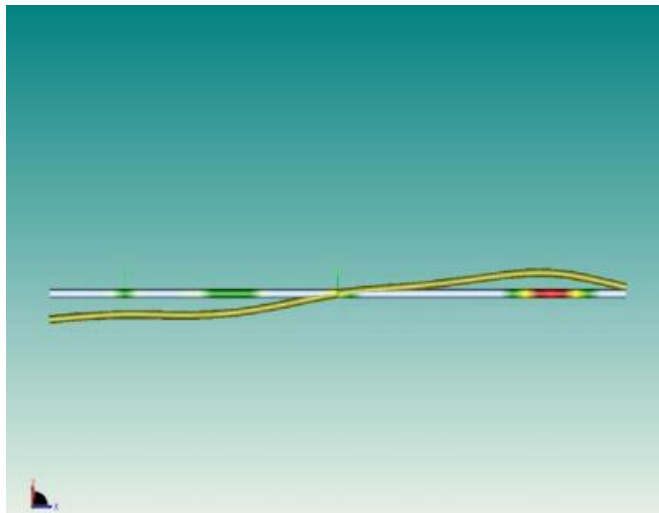


Figure 17. Deflection and maximum stress C1-LC1

4.1 Bending and tightness test

Bending and tightness test was carried out, in order to verify the mechanical resistance of the GRP pipe to the stresses induced by the launching methodology and at the same time the hydraulic seal of the joint. The maximum bending moment, which occurs during the launch in the "S" configuration, is: $M_b = 618'000 \text{ N m}$. The volumes of water inserted in the pair of pipes were determined by means of a liter counter. During this test several bending moments were realized, using one support-support configuration with joint locked in the center as shown in the figure 18, with a span $L = 22 \text{ m}$.

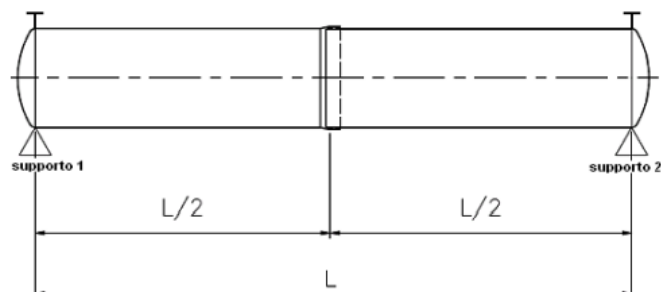


Figure 17. Bending test configuration

In the end of the test procedure, which lasted three days, the sample was filled to the maximum. In this condition the sample remained for about 1 hour. The arrow corresponding to the center for this load condition was $f = 352 \text{ mm}$.



Figure 18. The sample of the bending test

As a result a pair of full-size tubes were tested with the load to which the pipe will be subjected during the launching phases from the pontoon. The result of the test was very satisfactory, as the deformations even after about 70 hours were less than those theoretically expected and, at the same time, the joint passed the infra-O ring seal test. Subsequently it was decided to subject the pair of tubes to maximum stress achievable with the test configuration. Even in this configuration, the deformations found were lower than that foreseen by the theoretical calculation.

In the table 7 and the figure 19 (bending moment Nm vs time hours), are shown the comparison between the deformations found and the theoretical ones and the results of the test.

Step	Water volume	Support reaction	Bending moment M_b	Expected arrow in the middle	Measured arrow in the middle
	litri	Kg	Nm	mm	mm
MO	0	2585	142171	40	46
M1(1.00)	16746	10957	618882	173	71
M2(1.33)	23499	14446	821949	260	187
M3(1.50)	27528	16372	927000	272	210
M4(2.00)	36051	22023	1233703	362	342
M5(2.16)	44234	24701	1332271	423	352

Table 7. Comparison between the deformations found and the theoretical ones

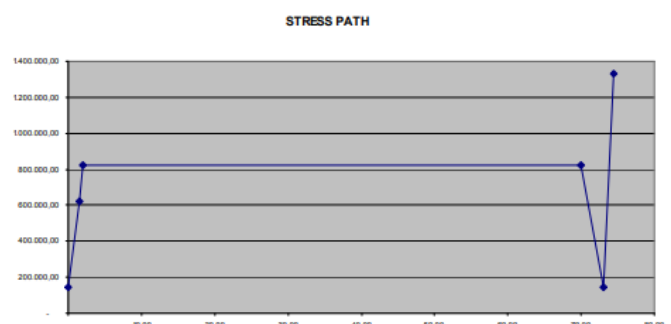


Figure 18. Stress path, bending moment vs time

5. Results and discussion

- From the calculations carried out, it was evident that the most critical effect on the GRP pipe was the one, by the position of the concentrated force due to the presence of sledge (approximately 2 tons), not disassembled from the string after moving the position from the shore.
- In these cases, where the central crane was maintained fixed or was moved downward, the maximum bending stress on the pipe was 12.03 MPa. Considering the transient (occasional) configuration valid for the floating of the string we obtained:
Transient condition (occasional load).
Pipe – Maximum bending stress $12.03 \text{ MPa} < \text{allowable}$

bending stress 14.82 MPa (81% of the allowable one).

Joint - - Maximum bending stress 12.03 MPa > allowable bending stress 9,39 MPa (128% of the allowable one).

- c. The load cases in which the movement of central crane is upward, are more critical compared to the previous one and we obtained a maximum bending stress of 14,85 MPa for load case no. 5. The comparison with the allowable ones is the following.
Pipe - Maximum bending stress 14.85 MPa = allowable bending stress 14.82 MPa (100% of the allowable one).
Joint - - Maximum bending stress 14.85 MPa > allowable bending stress 9,39 MPa (158% of the allowable one).
- d. According to the above results, the verification is OK for the pipe wall in the transient condition (occasional load) and for the joint shows, in the worst scenario, a bending stress 158% of the allowable one.
- e. In this case it is possible to have the crack of the resin used for the freezing of the joint, but not the failure of the system joint + pipe, that can withstand without failure a stress 3 times greater than the allowable stress for the pipe according to EN1796.
- f. When the pipe is laid on the seabed, the moment will be zero and the joint maintains its hydraulic properties ensuring the sealing through the O-Rings.
- g. In order to be sure we have simulated the increase of bending moment on a Bell/Spigot joint positioned in the middle of a span of 22 m (2 pipes, as explained here above). The test was Ok and no failure of joint and pipe was observed at 2,16 times the maximum theoretical bending moment (2,16 times was due to limitation in the equipment). At the same time the hydraulic test of the joint was carried out without any leakage.

6. Conclusion

After the root cause analysis a hydraulic design review was carried out including:

- a. Hydrodynamic condition
Waves, water levels, currents, temperature
- b. Seabed stability
Bed mobility, seasonal changes, scour
- c. Sediment suspension
Concentration profile, ingress rate
- d. Pipe hydrodynamics
Hydraulic gradient, sediment transporting capacity
- e. Temperature spread near the diffuser
- f. Sea state analysis
- g. In service bottom stability

The results found were used to upgrade the methodology of the pipeline installation. A detailed analysis of sinking of pipe string was carried out using CAESAR II software and considering different load cases.

The installation of the pipelines were carried out successfully.

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Modeling and experimental evaluation of the possibility of using a radial-shear rolling mill for recycling bar scrap of ferrous metals

Lezhnev Sergey¹; Naizabekov Abdrakhman¹; Panin Evgeniy²; Kuis Dmitry³; Kasperovich Andrey³
¹ Rudny industrial institute, Rudny, Kazakhstan; ² Karaganda industrial University, Temirtau, Kazakhstan
³ Belarusian state technological university, Minsk, Belarus
 e-mail: sergey_legnev@mail.ru

Abstract: This work is devoted to the study of the use of radial-shear rolling mills for recycling bar scrap and some metal products from ferrous and non-ferrous metals that have served their service life to obtain a ready-made commercial product. In particular, the paper presents the results of computer modeling and experimental research of the process of scrap metal rolling in the form of rebar on a radial-shear rolling mill into a round cross-section bar, which prove that some metal products that have served their service life after recycling using the proposed technology into finished commercial products in the form of bars can find further use without remelting.

Keywords: RECYCLING, BAR SCRAP, RADIAL-SHEAR ROLLING, COMPUTER MODELING, EXPERIMENT.

1. Introduction

One of the most important problems in the field of environmental protection is the problem of waste recycling from various industries and their further consumption. Therefore, for more than a decade, much attention has been paid around the world to the development of various methods not only for waste disposal (including scrap metal), but also for their processing, i.e. recycling.

"Iron garbage" is a special category of waste, which is called scrap metal. The ideal modern solution for recycling scrap metal is to recycle it for further use for human needs.

One of the easiest ways to process ferrous metal and alloy scrap is its remelting and further reuse. However, in some countries of the world, another method of processing it has also come into practice - recycling of some metal products that have served their service life by various methods of hot pressure treatment to obtain a ready-made marketable product [1-4]. Recently, a fairly new method of processing failed metal products by deforming them in the hot state on radial-shear rolling mills is also widely used [5-7].

The direction of radial-shear rolling began its development at NUST MISIS by S.P. Galkin and is a three-roll screw rolling scheme, similar to the scheme used for piercing pipes in the pipe rolling industry. The main difference between the scheme proposed by S.P. Galkin is the feed angle increased to $\alpha = 18^\circ - 20^\circ$ at the usual rolling angle $\beta = 5^\circ$ [8]. This is what contributes to the development of the strongest vortex deformation from the surface to the center when implementing radial-shear rolling, and the ability to avoid the appearance of tensile stresses in the axial part of the workpiece. Based on the proposed radial-shear rolling scheme, a number of rolling mills at NUST MISIS were developed and put into small-scale production.

It is proposed to use the technology of radial-shear rolling for processing ordinary ferrous metal scrap in order to obtain a high-quality commercial product in the form of bars of circular cross-section. Currently, Kazakhstan's metal bases that accept scrap metal have a large number of different black scrap, including bar scrap, which could also be processed at a radial-shear rolling mill to obtain high-quality bars with a fine-grained structure and an increased level of mechanical properties.

The purpose of this work is a theoretical (using computer modeling in the DEFORM software package) and experimental study of the possibility of using radial-shear rolling mills for recycling bar scrap in the form of rebar to obtain a ready-made commercial product.

2. Computer modelling

At the first stage, during computer modeling in the DEFORM software package, it was decided to use the parameters of the existing SVP-08 mill installed at the Rudny industrial institute to create a model of radial-shear rolling. The initial billet was a reinforcing bar with a diameter of 30 mm and a length of 250 mm (Figure 1).

As the workpiece material a stainless steel AISI-1015 was chosen, heating temperature was 1000°C; rolling speed was set to 50 rpm as the nominal value of the SVP-08 mill. The friction

coefficient on contact of the workpiece and the rolls was adopted equal to 0.7, as recommended for hot-rolling rolls with roughened surface. As a result, the resulting model of the rolls of the SVP-08 mill had the form shown in Figure 2.

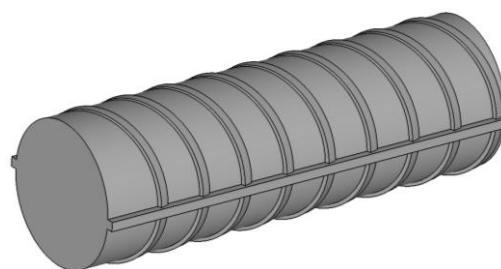


Fig. 1 Workpiece geometry for modeling



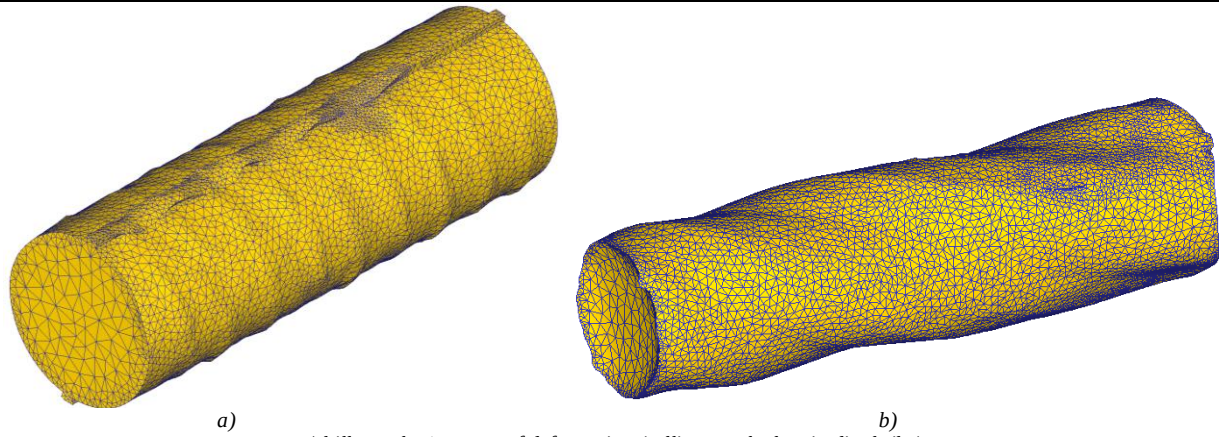
Fig. 2 Model of rolls of radial-shear rolling mill

To model the new recycling method, which includes successive stages of radial-shear rolling, it was decided to perform deformation according to the following scheme:

1) at the initial stage, radial-shear rolling is carried out at small compressions (0.5-1 mm per pass) in order to remove the longitudinal ribs of the reinforcement profile;

2) after removing the longitudinal ribs, the compression value increases to 3÷3.5 mm per pass for rolling out the transverse ribs and intensive processing of the surface layer of the workpiece.

The results of modeling these two stages are shown in Figure 3. Despite the fact that rolling with intensive compressions proceeded quite stably due to the absence of longitudinal ribs on the workpiece, the final shape of the workpiece can not be called "commodity" - it has a distinct spiral contour. This surface is created as a result of the intensification of compression. However, if when rolling an ordinary round billet, this contour will be barely noticeable (due to a more uniform distribution of deformation when rolling a billet of the correct shape), then in this case, rolling at increased compressions leads to a strong spiral surface relief.



a) billet at the 1st stage of deformation (rolling out the longitudinal ribs);
b) billet at the 2nd stage of deformation (rolling out the transverse ribs and intensive radial-shear rolling)
Fig. 3 Shape of the reinforcement profile during deformation at the radial-shear rolling mill

Therefore, it was decided to conduct additional modeling of the second stage of deformation, where rolling will be carried out at the same small compressions as in the first stage of deformation. In this case, the number of deformation cycles will increase. Figure 4 shows the billet after a series of passes with small compressions.

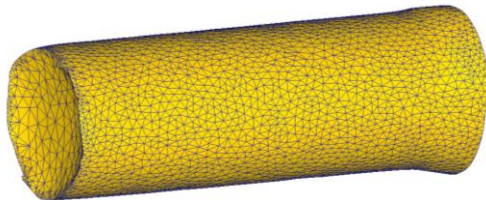


Fig. 4 Billet at the 2nd stage of deformation when using small compressions

It is clearly visible that after applying the small compression mode, the overall appearance of the workpiece has acquired the correct round profile. Therefore, it can be concluded that for recycling bar scrap in the form of reinforcement to obtain a finished product of the correct geometric shape using radial-shear rolling, it is necessary to carry out rolling at small compressions at all stages of deformation.

3. Experiment

At the second stage of research, a physical experiment was performed at the SVP-08 radial-shear rolling mill to confirm the possibility of implementing the proposed technology for recycling ferrous scrap in practice (Figure 5).



Fig. 5 Rebar rolling process at the SVP-08 mill

As the initial blanks, as in the simulation, pieces of rebar made of steel St5sp of A-II class (A300) GOST 5781-82 with a diameter of 30 mm and a length of 250 mm were used (Figure 6a). Before deformation, these pieces of rebar were heated in a Nabertherm R120/1000/13 tube furnace to a temperature of 1000°C with an exposure time of 30 minutes. Subsequent deformation of the heated samples was carried out on the SVP-08 radial shear rolling mill up to a diameter of 20 mm in five passes with an absolute compression step of 2 mm in diameter.

During the process of deformation of the reinforcement profile with a diameter of 30 mm on a radial-shear rolling mill, a rod with a diameter of 20 mm was obtained. Figure 6b shows that there is a slight curvature of this bar, so when the proposed technology is introduced into production, to give the bar the necessary

straightness after reaching the required diameter, it will be edited on a special rolling mill [6].

4. Conclusion

The conducted simulation together with a physical experiment confirmed the possibility of processing various ferrous scrap bars, including rebar, to obtain a marketable product in the form of a metal bar.

5. Acknowledgments

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Fig. 6 Bar scrap (reinforcement profile) before (a) and after (b) rolling

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Alternative possibilities for application of foamed silicate materials

Lyuben Lakov¹, Bojidar Jivov¹, Yonka Ivanova^{*2,3}, Stanko Yordanov¹, Krasimira Toncheva¹

¹ Bulgarian Academy of Sciences, Institute of Metal Science, Equipment and Technologies with Hydro- and Aerodynamics Centre "Acad. A. Balevski", 67 Shipchenski prohod st., 1574 Sofia, Bulgaria,
e-mail: krasiton4@abv.bg

² Sofia University "St. Kliment Ohridski", Faculty of Physics, Department of Nuclear Engineering, Sofia, Bulgaria

³ Institute of Mechanics at the Bulgarian Academy of Sciences, Sofia, Bulgaria,
e-mail: yonivan@phys.uni-sofia.bg

Abstract: In summary form, some trends in the production and application of foamed silicate materials obtained from recycled waste materials are presented. The existing possibilities for the use of different fractions of foam glass granules for the preparation of various products (lightweight concrete, colored decorative panels, etc.) are considered. Experimental samples are prepared in which the average value of the thermal conductivity coefficient $\lambda=0.24\pm0.13$ W/m. K was established. The main technological factors determining the operational characteristics of the material and the existing potential prospects for their optimization are analyzed.

Keywords: GLASS WASTE, FOAMED SILICATE MATERIALS, LIGHTWEIGHT AGGREGATES

1. Introduction

The development of new materials and technological methods allows the production of products with different functional characteristics and application [1-10]. Due to the growing quantities of household and industrial waste products, the development of ecological technologies for cost-effective recycling of waste raw materials and production of competitive ware is of interest. The presence of glass waste materials that are not fully utilized is a prerequisite for finding suitable opportunities for their recycling. The possibilities for obtaining various silicate foam products from glass waste raw materials of different origin have been studied. The effect of the introduction of various foaming agents in the compositions and the role of the applied thermal treatment on the processes of foaming and pore formation have been established [11,12]. Based on the obtained data, recipe compositions and an adequate technological regime (for obtaining products) have been developed, in accordance with the specifics of the used waste silicate raw material and the foaming agent [12].

Various foam glass products are used in the insulation of buildings, equipment, facilities, pipelines and other objects [12]. At the same time, foam glass gravel is applicable in the field of road construction and landscape design.

The foaming ability of deep-water organogenic-mineral sediments and their use as a foaming agent for the preparation of foam glass samples from waste glass are studied [13].

A promising approach for obtaining silicate foam products is the utilization of waste raw materials obtained from various production activities. The foaming ability of amorphous-crystalline polyphase waste product from the energetics, characterized by the presence of different phases: glass phase, $\text{Al}_6\text{Si}_2\text{O}_8$, $\text{CaAl}_2\text{Si}_2\text{O}_8$, $\alpha\text{-SiO}_2$, Fe_3O_4 , $\alpha\text{-Fe}_2\text{O}_3$ and other phases was studied. Thermal treatment (up to 1100°C) of the raw material without the introduction of foaming agent resulted in polyphase foam products with the presence of aluminosilicates (mainly mullite $\text{Al}_6\text{Si}_2\text{O}_8$) and other crystalline phases [14].

An insulating material has been developed with the participation of foam glass granules (obtained from waste glass raw materials), inorganic hydraulic binder and technological additives. The material is applicable for the production of various profiles, non-bearing panels and others [15].

Thermal insulation material is obtained by thermal treatment of samples prepared from deep-water organogenic mineral sediments and foam glass granules distributed in the volume of the material [16].

Due to their specific characteristics, some foam glass materials can be considered as alternative substitutes to a number of classic lightweight aggregates. In this aspect, it is of interest to study the possibilities for the application of foam glass granules in the preparation of lightweight concrete [17] for construction.

Another approach for the application of foam glass materials is the production of foam silicate granules with different color characteristics and their use for the preparation of panels.

The aim of the present work is to establish the coefficient of thermal conductivity of experimental samples obtained from foam glass granules and Portland cement. The technological factors determining the operational indicators of the material are analyzed and the possibilities for application of foamed silicate materials for the production of lightweight concrete and colored decorative panels for cladding of buildings are considered.

2. Experimental procedures

For the preparation of the necessary experimental samples, foam glass granules were obtained using a technological method of several stages: grinding of waste silicate glass, obtaining initial batch from glass powder and a suitable foaming agent, preparation of primary granulate, foaming of the obtained product up to form foam glass granules by applying thermal treatment to 900°C (with an soaking of 15 min) and sorting the granules by fractions. The necessary thermal treatment for foaming of the obtained primary granulate was performed in a programmable muffle furnace, equipped with an electronic programmer, providing determination of the speed ($5\text{-}10^\circ\text{C}/\text{min}$) of increase and decrease of the temperature values and the time of soaking.

A mixture of foam glass granules (fractions up to 20 mm in diameter) and pre-prepared Portland cement (CEM I 52.5 R) solution and water was prepared. At using compositions of several fractions of foam granules (of different sizes), the smaller ones are localized in the cavities formed between adjacent granules with a larger diameter. The bulk density of the samples increases with growing the introduced amount of granules with smaller sizes. The molding of the samples was done by laying the mixture in pre-prepared formwork forms. The obtained test specimens were stripped after 24 hours and after additional technological downtime were subjected to final machining to form cylindrical experimental specimens applicable to the present study.

The comparative method is used to measure materials with a low thermal conductivity, using comparative samples with a cylindrical shape [EN1225]. A comparative sample ($h_R=12$ mm, $D=120$ mm), test material ($L=65$ mm, $D=120$ mm), a second reference sample ($h_R=12$ mm, $D=120$ mm) and a cooler are placed successively on the heater. The diameters of the comparative samples and the test sample are the same ($D=120$ mm). The system is insulated with a material with a low coefficient of thermal conductivity. Figure 1 shows a scheme for implementing the comparative method for measuring the coefficient of thermal conductivity.

In fig. 1 the following designations are used: 1 - heater, 2,3 - comparative samples with cylindrical shape from material with high thermal conductivity (steel), 4-test sample, 5,6,7,8 - thermocouples for measuring temperatures type K, 10 - thermometer - registering

device for recording the change of temperatures with time (4-channel CENTER 304 type K thermometer).

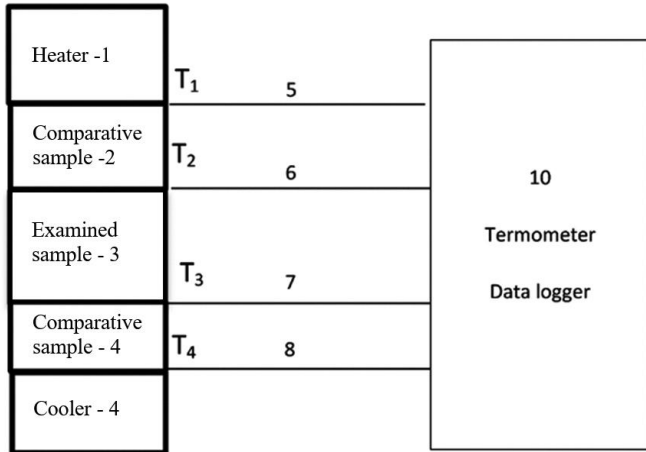


Fig. 1. Scheme of experimental installation.

The amount of heat Q that is conducted through a material of thickness h at a temperature difference ΔT at a time interval τ through an area S is determined by the dependence:

$$Q = \lambda \cdot S \cdot (\Delta T / h)$$

where λ is the coefficient of thermal conductivity of the material, and ΔT is the temperature difference of the two opposite surfaces.

At a stationary thermal regime, the amount of heat which passes from the heater through the comparative sample to the test piece and the second comparative sample, which have the same area, is the constant:

$$Q = \lambda_R \cdot \frac{\Delta T_{12}}{h_R} = \lambda_x \cdot \frac{\Delta T_{23}}{h_x} = \lambda_R \cdot \frac{\Delta T_{34}}{h_R};$$

where λ_R is the coefficient of thermal conductivity of the material of the comparative sample, λ_x is the coefficient of thermal conductivity of the test sample, ΔT_{12} is the temperature difference measured on the surface of the heater (1) and the comparative sample (2), ΔT_{23} is the temperature difference measured on the surfaces of the comparative (2) and the measured sample (3).

The coefficient of thermal conductivity λ of the material of the test sample is determined by the expression:

$$\lambda = \lambda_R \frac{\Delta T_{12}}{\Delta T_{23}} \cdot \frac{h_x}{h_R}.$$

3. Results and Discussion

The accuracy of the proposed method largely depends on the accuracy with which temperatures and temperature differences are determined, the accuracy with which λ_R is determined of the geometric dimensions of the samples. Sufficient time is required to create a constant temperature gradient in the studied system. The measurement is repeated many times and the data are processed statistically. The average values of the temperature in the two disks with which the studied material is in contact are determined. In fig. 2, 3 and 4 show the results of the temperature measurements.

At the laboratory tests of the prepared experimental samples, an average value of the thermal conductivity coefficient $\lambda=0.24 \pm 0.13$ W/m.K was registered.

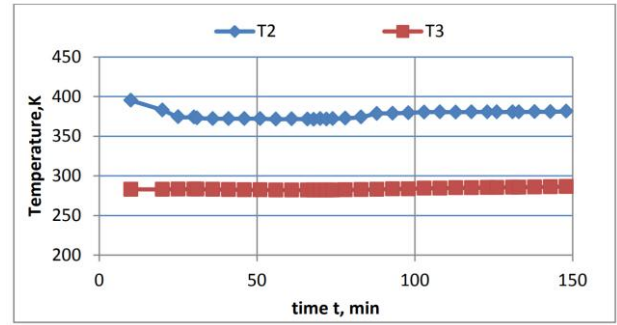


Fig. 2. Change in the surface temperature of the comparative sample (2) and the test sample (3) over time.

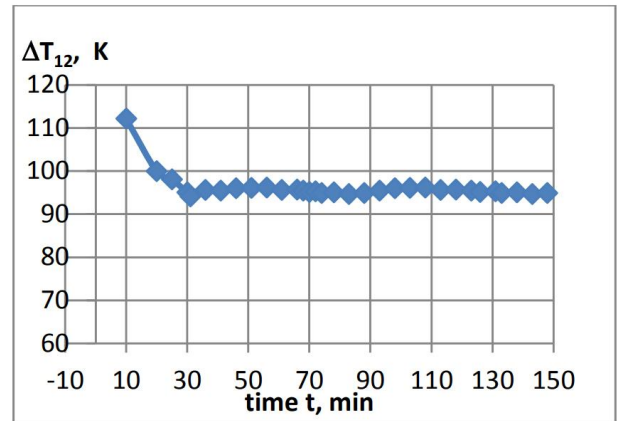


Fig. 3. Change of temperature differences ΔT_{12} with time t .

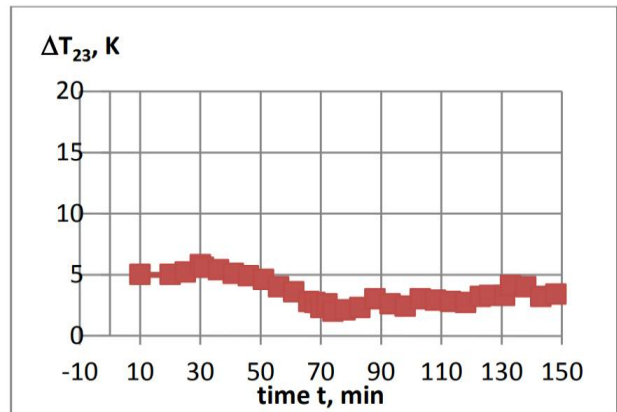


Fig. 4. Change of temperature differences ΔT_{23} with time t .

Based on the experimental data obtained from the present and previous studies, the main technological factors determining the characteristics of the product are analyzed: composition of the starting waste silicate raw material (glass waste), used foaming agent, presence of modifiers, used of plasticizers, composition of the prepared batches, heat treatment regime (applied in the preparation of the foam glass granules), degree of foaming of the obtained foam glass granules, granulometric composition of the used foam granules, used Portland cement, weight ratio of cement: granules, application of technological additives (air-entraining agents, water-reducing agents, zeolite, etc.), introduction of other components (river sand, etc.), technological parameters of the cement solution, characteristics of the obtained mixture granular-cement solution, introduction of reinforcing fibers (fiberglass fibers, basalt fibers, steel fibers, etc.), presence in the volume of the material of air cavities formed at the contact of adjacent foam glass granules, etc.

According to the necessary functional characteristics of the product, there are different possibilities for modifying the

compositions and changing the technological conditions for obtaining the product. Optimization of the performance of the material can be done by applying different technological approaches: increasing of the degree of foaming of the foam glass granules, appropriate ratio of the used fractions from granules, presence of different reinforcing components according to the used fractions of foam granules, removal of excess liquid phase at the end of the technological process and a number of others.

The applied technological method for obtaining the material has some main advantages: recycling of non-degradable in natural conditions waste silicate raw materials, use of available standard materials (cement, etc.) with a relatively low cost, application of simple technological activities for the preparation of the samples, obtaining sustainable end product with a long service life.

A logical technological approach the use of different fractions of foam silicate granules as alternative substitutes for some classic lightweight aggregates (expanded clay, expanded perlite, vermiculite, etc.). Therefore, foam glass materials can be considered as suitable alternative components applicable to obtain of lightweight concretes and other products. The material is applicable for the production of monolithic products by casting in various formwork forms, as a filler for cavities, in the construction of flooring and various repair and construction activities. The obtained experimental results are a prerequisite for further development of various compositions for lightweight concrete with suitable characteristics.

Another original opportunity for the application of foam glass materials is the preparation of a palette of color patterns. Compositions suitable for the production of foam silicate granules with various color characteristics have been developed by introducing colorants in the initial compositions. From the prepared colored silicate granules and inorganic hydraulic binders prototypes of panels potentially applicable for decorative cladding of buildings and other architectural objects were made.

4. Conclusions

Experimental samples of foam glass granules (obtained from waste silicate materials) and Portland cement were prepared, in which the average value of the thermal conductivity coefficient $\lambda=0.24\pm0.13$ W/m.K was experimentally established by applying the comparative method.

The functional characteristics of the material and the possibilities for their optimization are determined by a number of technological factors: starting prescription compositions, specifics of the foaming agent, heat treatment regime, degree of foaming of the prepared granules, ratio of different fractions of foam glass granules used, Portland cement used, weight ratio cement: granules, introduction of technological additives, application of reinforcing fibers, technological parameters of the prepared cement solution and the resulting mixture of granules-cement mortar and others.

A promising environmental solution is the use of foam glass granules (derived from glass waste) as an alternative component, replacing some standard lightweight aggregates in the manufacture of lightweight concrete and other products.

By introducing colorants to the starting compositions, foam silicate granules with different color characteristics were obtained. From the obtained colored silicate samples and inorganic hydraulic binders are made panels, potentially applicable for decorative cladding of buildings.

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Thermodynamic analysis of a 500 MW ultra-supercritical pulverized coal power plant

Bruno Mišić, Paolo Blečić
University of Rijeka, Faculty of Engineering
Vukovarska 58, HR-51000 Rijeka, Croatia
paolo.blecich@riteh.hr

Abstract: This paper analyses the performance of a future planned 500 MW ultra-supercritical pulverized coal power plant. The steam cycle configuration comprises a single-stage reheat, four high pressure feedwater heaters, three low pressure feedwater heaters and the deaerator. The electricity generation unit consists of a high pressure turbine, an intermediate pressure turbine, two double-flow low pressure turbines and the electric generator. The analysis is carried out for live steam temperature of 600 °C and pressure of 300 bar while the reheat steam temperature is 610 °C and the pressure is 50 bar. The condenser pressure is 0.039 bar. The analysis revealed that the ultra-supercritical power plant achieves a gross thermal efficiency of 47.39% and a net thermal efficiency of 45.14%. The specific CO₂ emissions per unit of generated electricity are 733.4 kg/MWh. Relatively to existing subcritical units, the analyzed ultra-supercritical power plant achieves a net efficiency gain of 9%-pts. and a CO₂ emission reduction of around 20%.

Keywords: ULTRA-SUPERCRITICAL STEAM CYCLE, PULVERIZED COAL, NET EFFICIENCY GAIN, CO₂ EMISSIONS REDUCTION

1. Introduction

Fossil fuels are still the dominant energy source for electricity generation but declining under the accelerating expansion of renewable energy sources in the last decade. In 2019, the global generated electricity was 27005 TWh [1]. Conventional energy sources generated 74% of the worldwide electricity, whereas coal generated 9945 TWh (36.8%). The countries with more than 150 TWh of generated electricity from coal power plants are the big economies such as China (4854 TWh), India (1137 TWh), USA (1054 TWh), Japan (326 TWh), South Korea (239 TWh), South Africa (217 TWh), Russia (182 TWh), Indonesia (177 TWh), Germany (171 TWh) and Australia (150 TWh). Among the other conventional energy sources, natural gas generated 6376 TWh (23.6%) of electricity, oil 835 TWh (3.1%) and nuclear 2830 TWh (10.5%). Renewable energy contributed with 26% to the total worldwide electricity: large hydro generated 4222 TWh (15.6%) of electricity, wind power 1430 TWh (5.3%), solar power 724 TWh (2.7%) while biomass and geothermal added 652 TWh (2.4%) [1].

The total global proved reserves of coal are estimated at 1070 billion tonnes, of which bituminous coal and anthracite represent 750 billion tonnes while sub-bituminous coal and lignite represent 320 billion tonnes. The proved coal reserves are those reserves that can be recovered with reasonable certainty using existing technologies and under acceptable economic conditions. With the present production rates, the proved reserves of coal are estimated to last 130 years. Almost two-thirds of the proved coal reserves are concentrated in four countries: USA (23%), Russia (15%), Australia (14%) and China (13%). At global scale, the total coal consumption rate is increasing, at an average growth rate of 0.8% per year. Most of this coal consumption growth is coming from China and India where the annual growth rates are 1.7% and 5.5%, respectively. Conversely, coal consumption is declining in the US (−5.1%) and in the EU (−3.0%), under the increasing environmental and climate change concerns. Coal-fired electricity generation is the single largest source of greenhouse gases. In 2018, total global CO₂ emissions caused by fuel combustion were estimated at 34 Gt, whereas coal-fired electricity generation was responsible for more than 10 Gt of CO₂. Coal-fired power plant generate specific CO₂ emissions between 877 and 1130 kg/MWh per unit of electricity. These carbon emissions are twice as much as the emissions from natural gas power plants (422 – 548 kg/MWh) and up to twenty times the emissions from wind power (8 – 20 kg/MWh), geothermal power (20 – 57 kg/MWh) and solar PV (29 – 80 kg/MWh).

The IEA sustainable development scenario predicts the reduction of CO₂ emissions from the coal-fired power plants by as much as 50% by 2030 [2]. In order to halve coal-fired emissions in the next decade, existing coal power plants will be either retrofitted with biomass co-firing or carbon capture and storage (CCS) technology or discontinued. However, the share of advanced coal-fired technologies is expected to grow in order to meet the ongoing

growth in global electricity demand [2]. These advanced coal-fired technologies include supercritical coal power plants, integrated gasification combined cycles (IGCC), coal-fired units upgraded with oxy-fuel combustion, pre-combustion and post-combustion capture, utilization and storage of carbon dioxide (CCUS) [3].

Subcritical power plants (SUBC) achieve thermal efficiency in the range between 34% and 40% (based on coal LHV) with the global average efficiency around 36% [4]. On the other side, modern supercritical power plants (SC) reach efficiencies between 42% and 45% [5]. Ultra-supercritical power plants (USC) achieve even higher thermal efficiencies [6] by employing advanced metal alloys capable of withstanding extreme steam temperatures and pressures [7-8]. A record-high net efficiency of 47.5% was achieved by the RDK Block 8 unit in Germany. The RDK Block 8 uses superheated steam having temperature of 600 °C and pressure of 275 bar at the turbine inlet. Future planned ultra-supercritical coal power plants will approach net electricity efficiency of 50% [9].

Increased thermal efficiency results in reduced CO₂ emissions. Ultra-supercritical power plants are expected to achieve a 10%-pts efficiency gain over conventional coal power plants. While a conventional coal power plant achieves 36% net efficiency, an ultra-supercritical (USC) unit would reach 45% net efficiency. In other words, the USC unit generates 25% ($0.45/0.36 = 1.25$) more electricity than the subcritical unit per unit of fuel heat input. If the conventional unit emits CO₂ at a rate of 900 kg/MWh, the USC unit would emit CO₂ at a rate of 720 kg/MWh ($900/1.25 = 720$). The supercritical unit achieves a CO₂ emission reduction of 20% over the subcritical unit.

2. The ultra-supercritical coal power plant

Figure 1 shows the configuration of the analyzed supercritical steam cycle. This configuration comprises a single-stage reheat and eight feedwater heaters (FWH). Three feedwater heaters (FWH 1-3) and the deaerator are placed between the condenser and the feedwater pump (FWP), in the low-pressure preheating line. Four feedwater heaters (FWH 4-7) are placed between the feedwater pump and the steam generator, in the high-pressure preheating line. The steam enthalpy content is transformed into useful work in the high pressure (HP) turbine, in the intermediate pressure (IP) turbine and two double-flow low pressure (LP) turbines, which drive the electric generator. The electromechanical efficiency of the electric generator is assumed 0.98 [10].

The steam generator produces superheated steam at a temperature of 600 °C and pressure of 300 bar, state ①. The total thermal losses of the steam generator (flue gases, ash, radiative heat losses) are set at 5% of the fuel LHV input, returning an efficiency of the 0.95. In the high pressure (HP) turbine, steam expands to the cold reheat pressure of 50 bar, state ③. The cold reheat ⑤ is brought into the boiler reheat section and enters the IP turbine at state ⑥. In the IP turbine, steam expands to state ⑩ and is brought

to the LP turbines where it expands to state (17). The turbine isentropic efficiency, including inlet valve losses, is 0.90 for the HP turbine, 0.94 for the IP turbine, and 0.885 for the LP turbines [10]. The moisture content in the exhaust steam (17) is 0.1 (steam quality 0.9) and depends on the reheat pressure in (6). Generally, the steam reheat pressure is limited to one-fifth of the live steam pressure to prevent excessive moisture contents in the exhaust steam. Higher reheat pressure could increase the steam cycle efficiency but at the cost of faster turbine blade erosion in the last stages of the LP turbines. Inside the water-cooled condenser, exhaust steam is turned into liquid condensate (18). Waste heat from the condenser is rejected into the atmosphere by wet cooling towers. It is assumed that the cooling water temperature increases 8 °C in the condenser. The cooling water inlet and outlet temperatures are calculated assuming a cooling tower efficiency of 75% at ambient temperature of 20 °C and relative humidity of 50%. The difference between the condenser steam saturation temperature and the cooling water outlet temperature is 4 °C. These assumptions return a condenser pressure is 0.039 bar, whereas the cooling water temperature is 16.4 °C (37) at the inlet and 24.4 °C (38) at the outlet.

After the condenser, the condensate pump (CP) sends feedwater to the LP preheating train, (19). The isentropic efficiency of the CP is assumed 0.80. The low-pressure feedwater heaters (FWHs 1-3) are heated by steam extractions (14), (15) and (16) from the LP turbines. Passing from one to the next FWH, feedwater is heated to states (21), (23), and (25). The deaerator removes dissolved oxygen and other gases while heating feedwater to (26) using steam extracted from the IP turbine (9). The deaerator is a direct-contact heat exchanger inside which feedwater mixes with superheat steam. The FWP pumps feedwater up to the pressure in the steam generator and provides the water head necessary to match pressure losses in pipes and FWHs (27). The isentropic efficiency of the FWP is assumed 0.85. The pressure drop in the steam generator is assumed 50 bar for main steam and 5 bar for reheat steam [10]. The pressure drop in the steam pipes is 0.03, expressed as fraction of inlet steam pressure. The FWP is not electric-driven but instead a feedwater pump turbine (FWPT) supplies the necessary power for FWP operation. The FWPT uses low-pressure steam extracted from the IP/LP crossover pipe (11). The FWPT isentropic efficiency is assumed 0.90. Exhaust steam from the FWPT (36) is sent to the condenser.

Table 1. gives the list of assumptions and input parameters for the analysis of the ultra-supercritical coal-fired power plant.

Table 1: Input parameters for the USC coal power plant

Parameter	Value
Fuel type: bituminous coal	
Coal composition:	carbon (C)
	hydrogen (H)
	oxygen (C)
	nitrogen (N)
	sulfur (C)
	ash
	moisture
	coal LHV
Net electric power	500 MW
Superheat steam temperature	600 °C
Superheat steam pressure	300 bar
Reheat steam temperature	610 °C
Reheat steam pressure	50 bar
IP/LP crossover pressure	5 bar
Turbine isentropic efficiency	HP turbine
	IP turbine
	LP turbines
Steam pressure drop	superheat line
	reheat line
	steam pipes
Steam generator efficiency (LHV based)	95
Generator electromechanical efficiency	0.98
Feedwater pump (FWP) isentropic efficiency	0.85
Condensate pump (CP) isentropic efficiency	0.80
FWP turbine isentropic efficiency	0.90
Feedwater heater (FWH) approach temperature	cold end
	hot end
Feedwater pressure drop in FWH	1 bar
Cooling tower efficiency	75%
Cooling water temperature difference	8 °C
Condenser approach temperature	5 °C
Ambient air temperature	20 °C
Ambient air relative humidity	50%
Auxiliary power need (% of net electricity)	5%

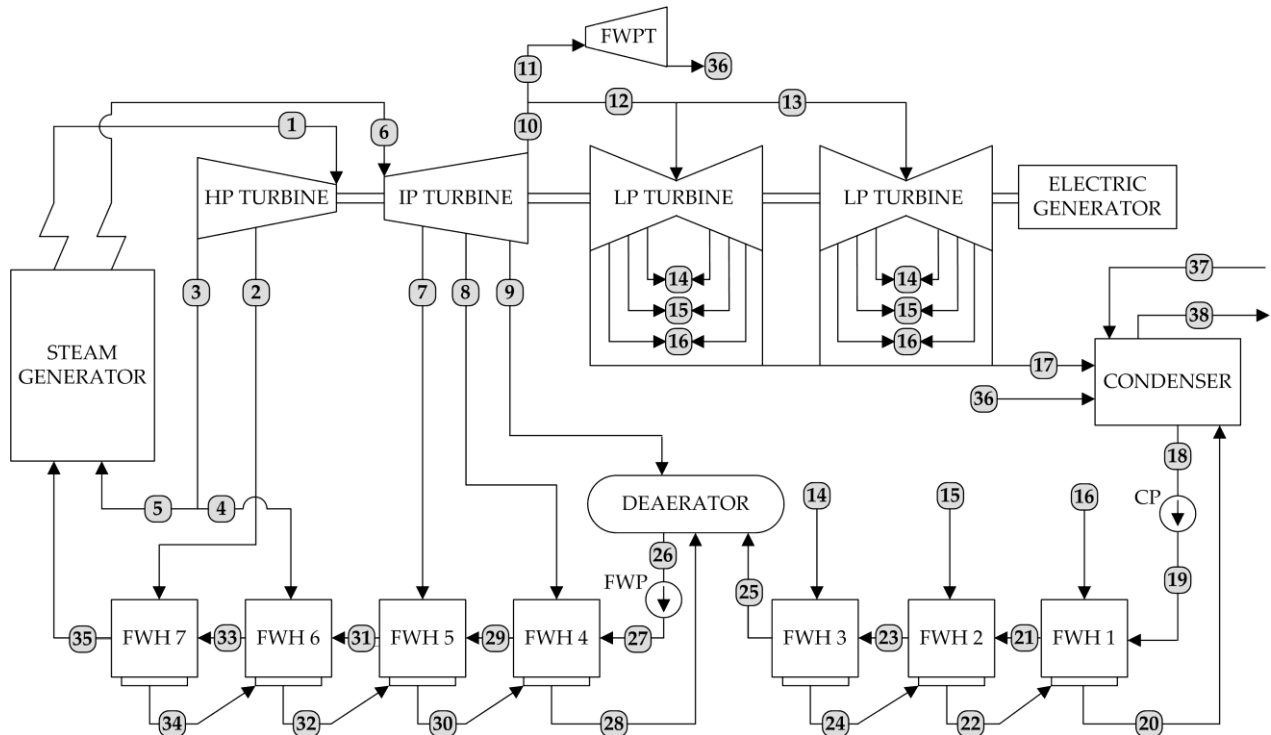


Fig. 1. The steam cycle configuration for the 500 MW ultra-supercritical coal-fired power plant

In the HP preheating train, feedwater is subsequently heated to states 29, 31, 33 and 35, before being evaporated and superheated in the steam generator. The high-pressure feedwater heaters FWHs 4-5 are heated by steam extractions 7 and 8 from the IP turbine while FWHs 6-7 are heated by steam extractions 2 and 4 from the HP turbine. All the FWHs are shell-and-tube heat exchangers, where feedwater flows in the tubes and the extracted steam flows in in the shell side. This steam is first desuperheated, then condensed and finally subcooled in the shell side. The outlet temperature of the subcooled liquid condensate is 5 °C above the feedwater inlet temperature. The feedwater outlet temperature is 2 °C below the steam saturation temperature at the steam extraction pressure. Water and steam properties are calculated using the IAPWS-IF97 standard built in the CoolProp database.

The input parameters necessary for thermodynamic calculations on the supercritical steam cycle is the power plant net electric power ($\dot{P}_{el,net,ref}$) of 500 MW, the coal composition, the superheat and reheat steam conditions, the isentropic efficiencies of turbines and pumps, the steam and feedwater pressure drops, the approach temperatures, all given in Table 1. The power plant gross electric power ($\dot{P}_{el,gross,ref}$) is obtained adding auxiliary power ($\dot{P}_{el,aux,ref}$) to the net electric power.

$$\dot{P}_{el,gross} = \dot{P}_{el,net} + \dot{P}_{el,aux} \quad (1)$$

The auxiliary power is necessary for the operation of combustion air fans, flue gases fans, cooling tower fans, mill grinders, flue gas treatment (electrostatic precipitators, DeSOx and DeNOx treatment), cooling water pumps, condensate pumps, water treatment, and ash handling. Generally, the auxiliary power needs represent 4-6% of the power plant electric power, feedwater pumps (FWP) excluded. In the present study, the auxiliary power is assumed 5% of the net electric capacity, that is 25 MW. The FWP is not accounted for in the auxiliary power since the necessary work is provided by the FWP turbine running on steam extraction from the IP/LP crossover (Figure 1.). The live steam mass flow rate is determined from the gross electric capacity and the mechanical work obtained in the HP, IP, and LP turbines, taking into account the electric generator electromechanical efficiency (η_{gm})

$$\dot{m}_{steam} = \frac{\dot{P}_{el,gross}}{\eta_{gm} \sum_i \left(1 - \sum_j \varepsilon_j\right) (h_{i-1} - h_i)} \quad (2)$$

The live steam mass flow rate $\dot{m}_{steam}$ produced in the steam generator is reduced by the steam extractions in the HP, IP and LP turbines. A total of nine steam extractions exist in the steam cycle configuration in figure 1: two from the HP turbine ($\varepsilon_2, \varepsilon_4$), three from the IP turbine ($\varepsilon_7, \varepsilon_8, \varepsilon_9$), one from the IP/LP crossover pipe (ε_{11}) and three from the LP turbines ($\varepsilon_{14}, \varepsilon_{15}, \varepsilon_{16}$). The enthalpy difference ($h_{i-1} - h_i$) in equation (2) is the actual steam enthalpy drop obtained as the product of isentropic enthalpy drop and turbine isentropic efficiency. The fuel heat input (LHV) is the sum of the heating duties for steam superheat and reheat, supplied in the steam generator by the coal LHV content at an efficiency of η_{sg}

$$\dot{Q}_{fuel} = \frac{\overbrace{\dot{m}_{steam} (h_1 - h_{36})}^{superheat} + \overbrace{\dot{m}_{steam} (1 - \varepsilon_2 - \varepsilon_4) (h_6 - h_5)}^{reheat}}{\eta_{sg}} \quad (3)$$

The power generated by the HP and IP turbines are

$$\dot{P}_{T,HP} = \dot{m}_{steam} \left[(h_1 - h_{2s}) + (1 - \varepsilon_2) (h_2 - h_{3s}) \right] \eta_{T,HP} \quad (4)$$

$$\dot{P}_{T,IP} = \dot{m}_{steam} \left[\begin{aligned} &(1 - \varepsilon_2 - \varepsilon_4) (h_6 - h_{7s}) + \\ &(1 - \varepsilon_2 - \varepsilon_4 - \varepsilon_7) (h_7 - h_{8s}) + \\ &(1 - \varepsilon_2 - \varepsilon_4 - \varepsilon_7 - \varepsilon_8) (h_8 - h_{9s}) + \\ &(1 - \varepsilon_2 - \varepsilon_4 - \varepsilon_7 - \varepsilon_8 - \varepsilon_9) (h_9 - h_{10s}) \end{aligned} \right] \eta_{T,IP} \quad (5)$$

The sum of the steam extraction from the HP and IP turbines is

$$\varepsilon_{HP+IP} = (\varepsilon_2 + \varepsilon_4) + (\varepsilon_7 + \varepsilon_8 + \varepsilon_9) \quad (6)$$

The power generated in the LP turbines is

$$\dot{P}_{T,LP} = \dot{m}_{steam} \left[\begin{aligned} &(1 - \varepsilon_{HP+IP} - \varepsilon_{11}) (h_{12} - h_{14s}) + \\ &(1 - \varepsilon_{HP+IP} - \varepsilon_{11} - \varepsilon_{14}) (h_{14} - h_{15s}) + \\ &(1 - \varepsilon_{HP+IP} - \varepsilon_{11} - \varepsilon_{14} - \varepsilon_{15}) (h_{15} - h_{16s}) + \\ &(1 - \varepsilon_{HP+IP} - \varepsilon_{11} - \varepsilon_{14} - \varepsilon_{15} - \varepsilon_{16}) (h_{15} - h_{16s}) \end{aligned} \right] \eta_{T,LP} \quad (7)$$

The FWPT drives the FWP by using steam extracted from the IP/LP crossover pipe. The quantity of extracted steam is determined from the equation that equates the FWPT generated power to the FWP consumed power

$$\dot{P}_{FWP} = \dot{P}_{FWPT} \rightarrow \begin{cases} \frac{\dot{m}_{FW} (h_{27s} - h_{26})}{\eta_{FWP}} = \dot{m}_{11} (h_{11} - h_{36s}) \eta_{FWPT} \eta_{gm} \\ \text{where: } \dot{m}_{FW} = \dot{m}_{steam} \text{ and } \dot{m}_{11} = \varepsilon_{11} \dot{m}_{steam} \end{cases} \quad (8)$$

The power plant gross efficiency η_{gross} is obtained dividing the gross electric power by the coal LHV fuel heat input, that is

$$\eta_{gross} = \frac{\dot{P}_{el,gross}}{\dot{Q}_{fuel,LHV}} = \frac{(\dot{P}_{T,HP} + \dot{P}_{T,IP} + \dot{P}_{T,LP}) \eta_{gm}}{\dot{Q}_{fuel,LHV}} \quad (9)$$

The power plant net efficiency η_{net} is obtained including the auxiliary power consumption

$$\eta_{gross} = \frac{\dot{P}_{el,gross}}{\dot{Q}_{fuel,LHV}} = \frac{\dot{P}_{el,net} - \dot{P}_{el,aux}}{\dot{Q}_{fuel,LHV}} \quad (10)$$

3. Results and discussion

Figure 2 shows the temperature-entropy chart while Table 2 reports the $\dot{m}$ - p - T data for the analyzed ultra-supercritical steam cycle. This steam cycle configuration uses a single stage reheat, eight steam extractions for seven FWHs and one deaerator as well as one steam extraction for the FWPT. It can be seen that steam superheat occurs above the critical point (CP) of the water-steam phase change region. The main steam cycle processes are drawn with bold lines while the steam extraction are drawn with dashed lines. The saturated liquid line and the saturated vapor line are drawn with dotted lines. The gross power output obtained from the turbines is 535.7 MW: the HP turbine generates 166.1 MW, the IP turbine 208.6 MW and the LP turbines 170.0 MW. An additional 13.8 MW net electricity is generated by the FWPT, solely for powering the FWPs. This FWP consumption represents 2.8% of the power plant net electric power. The turbines gross power output is decreased due to electromechanical losses, which results in a gross electricity of 525 MW from the generator. The net electric power is 500 MW, given the assumption of 25 MW power duty in the power plant auxiliary consumers.

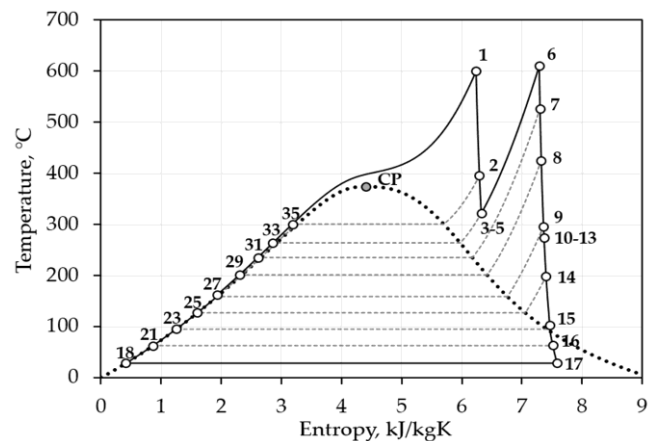


Fig. 2. Temperature-entropy chart of the USC steam cycle with superheat / reheat temperatures of 600 / 610 °C and pressures of 300 / 50 bar

The coal consumption is 42.12 kg/s (151.63 t/h) and the coal LHV is 26.3 MJ/kg, yielding a gross fuel heat rate of 1107.7 MW. This translates into a specific fuel heat rate of 7975.8 MJ_{th}/MW_{el} or 2.216 MW_{th}/MW_{el}. The steam generator supplies a net heat rate of 1052.4 MW to the steam cycle, obtained as the difference between the gross fuel heat rate and the heat losses in the steam generator ($\eta_{sg} = 0.95$). The live steam mass flow rate is 389.36 kg/s. The difference between the steam generator net heat rate (1052.4 MW) and the turbines gross power output (535.7 MW) is equal to the condenser thermal discharge (516.7 MW). The power plant gross efficiency is 47.39% and the net efficiency is 45.14%.

Table 2: Calculated m - p - T data for the USC steam cycle

Point	$\dot{m}$ (kg/s)	p (bar)	T (°C)	Point	$\dot{m}$ (kg/s)	p (bar)	T (°C)
1	389.36	300.00	600.00	20	44.08	0.23	33.55
2	31.71	89.42	399.95	21	279.47	19.00	60.85
3	357.65	55.00	333.87	22	29.95	0.85	65.85
4	26.85	55.00	333.87	23	279.47	18.00	93.04
5	330.80	55.00	333.87	24	15.26	2.47	98.04
6	330.80	50.00	610.00	25	279.47	17.00	124.98
7	18.47	31.69	531.92	26	389.36	6.00	158.83
8	17.79	16.42	429.84	27	389.36	354.00	164.18
9	15.07	6.19	299.72	28	94.82	15.93	169.18
10	279.47	5.00	274.56	29	389.36	353.00	199.16
11	25.08	4.85	274.34	30	77.03	30.74	204.16
12	-	-	-	31	389.36	352.00	233.21
13	254.39	4.85	274.34	32	58.56	53.35	238.21
14	15.26	2.54	205.78	33	389.36	351.00	266.03
15	14.69	0.87	111.56	34	31.71	86.74	271.03
16	14.13	0.23	$x=0.95$	35	389.36	350.00	298.71
17	210.31	0.04	$x=0.90$	36	25.08	0.04	$x=0.90$
18	279.47	0.04	28.39	37	15427.73	10.00	17.00
19	279.47	20.00	28.55	38	15427.73	2.00	25.00

The net efficiency of the analyzed USC steam cycle can be increased searching for the optimum reheat pressure. Figure 3 shows how the reheat pressure affects the steam cycle efficiency. For a live steam pressure (p_1) of 300 bar, the maximum steam cycle efficiency is obtained for reheat pressure (p_6) of 110 bar. However, this reheat pressure moves the expansion curve (6)–(17) to the left of the constant entropy line in the Ts -chart, resulting with a steam quality of $x = 0.85$ in the final point (17). Generally, steam turbines operate with maximum moisture contents of 12%, meaning that the lowest allowed steam quality is $x = 0.88$. This lowest steam quality is achieved already for a reheat pressure of 70 bar, that is for a live steam/reheat pressure ratio of 4.3. Nevertheless, the net efficiency is 45.58%, which represents a 1% relative increase over the baseline steam cycle with 45.14% net efficiency and 50 bar reheat pressure. The live steam pressure at the HP turbine inlet (p_1) also affects the steam cycle efficiency. The live steam pressures of 350 bar, 300 bar and 250 bar yield the respective net efficiencies of 45.83%, 45.58% and 45.13%, all for a fixed reheat pressure of 70 bar.

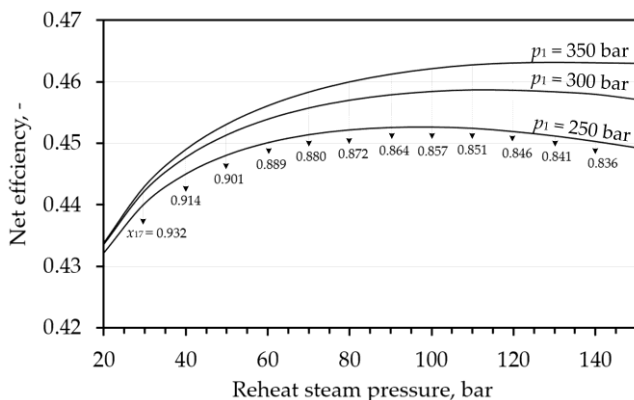


Fig. 3. The effect of reheat pressure on the USC steam cycle net efficiency

4. Conclusions

In the next decade, power plants employing ultra-supercritical coal and combined gas-steam cycle technologies are expected to replace conventional thermal power plants, especially in areas where a full shift to renewable electricity generation is not yet possible. Coal-fired ultra-supercritical steam cycles will achieve net efficiency of 45% or more. Steam generators, pipes and turbines will employ advanced metal alloys capable of withstanding extreme conditions, steam temperatures and pressures in excess of 600 °C and 300 bar. Relatively to subcritical units, ultra-supercritical units are expected to achieve around 10%-pts net efficiency gains and 20% carbon emissions reduction. Still, carbon emissions from ultra-supercritical coal power plants would be more than ten times larger than those from solar, wind and other renewable energy sources.

In the observed ultra-supercritical steam cycle, the flue gases quantity and composition can be determined from coal consumption and composition. The 500 MW unit would have a total flue gases mass flow rate of 1728.0 t/h, whereas nitrogen (N₂) participates with 1226.7 t/h, carbon dioxide (CO₂) with 366.7 t/h, water vapor (H₂O) with 70.0 t/h, oxygen (O₂) with 61.6 t/h and sulfur dioxide (SO₂) with 3.0 t/h. The specific CO₂ emission per unit of electricity would then be 733.4 kg/MWh. For comparison, existing subcritical coal stations generate electricity at specific CO₂ emissions of around 900-1000 kg/MWh [11]. The flue gases treatment of conventional coal power plants comprises electrostatic precipitators for fly ash removal, desulfurization unit for SO_x removal and the DeNO_x unit for nitrogen oxides removal. Future planned ultra-supercritical coal power plants will be coupled to carbon capture and storage (CCS) technologies, beside the standard flue gases treatments. CCS integrated USC coal-fired units could generate electricity with CO₂ emissions as low as 100 kg/MWh, a 90% reduction over units without CCS. However, further improvements in the carbon capture technology are necessary in order to alleviate the electricity output penalty caused by the large CCS energy demand.

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Modeling of the process of ultrasonic flaw detection of materials with internal microdefects of different origin

Kisil Tetyana, Bondarenko Maxim, Nesterenko Dmitro,
Cherkasy State Technological University

bulv. Shevchenka, 460, Cherkassy, 18006, Ukraine,

e-mail: kisiltetyana@ukr.net, maxxium23@gmail.com, diman23nesterenko@gmail.com,

Annotation. Miniaturization of technical products is one of the driving forces for the development of high-tech systems. The article considers the most well-known method of determining microdefects of microwelded joints - the method of ultrasonic flaw detection. It is known that microdefects weaken the cross-section of the micro-seam, reduce its strength and are stress concentrators. A dynamic computer model of ultrasound propagation in microwelded welds of metal containing defects of micrometric size of various shapes filled with gas (most often, air) was created. For ultrasonic control, oscillations with a frequency of 0.5 MHz and a direct transducer emitting longitudinal waves perpendicular to the contact surface into the welded joint were used. On the basis of results of computer modeling the regularity of sensitivity of measurement of microdefects from parameters of the ultrasonic microdefectoscope which with a high degree correlates with experimentally received data is revealed.

KEY WORDS: MINIATURIZATION, UNBRAKABLE CONTROL, WELD, MICRODEFECT, ULTRASONIC FLAW DETECTION, MICRODEFECTOSCOPE, DIRECT PIEZOELECTRIC TRANSDUCER, COMPUTER MODELLING.

Introduction

At present, special attention is paid to the introduction of automated methods for quality control of welded joints. A special program has been developed and is being implemented to introduce modern methods and means of non-destructive testing (NDT) into welding production. The traditional methods of control are also being further developed: radiation, ultrasonic, magnetic and capillary flaw detection [1].

Ultrasonic testing is an examination that is able to identify in the shortest possible time:

- ✓ wear of products,
- ✓ surface or internal defects of metals and alloys,
- ✓ the quality of the product or individual weld.

As you know, ultrasonic flaw detection is based on the property of ultrasonic waves directed to propagate in media and reflect from their boundaries or discontinuities (defects), which have a different acoustic resistance [2]. In practice, the quality control of welded joints is mainly used by the echo-pulse method (echo-location method), which consists in "sounding" the welded joint with short ultrasound pulses 1 and recording echo signals 2 (Fig. 1, a, b). and 3 (Fig. 1, b), reflected from the lower surface of the part and the defect to the receiver. An indication of the presence of a defect in the welded joint is the appearance of an echo signal 3 on the flaw detector screen. In some cases, it is advisable to carry out control using the shadow method (Fig. 1, b).

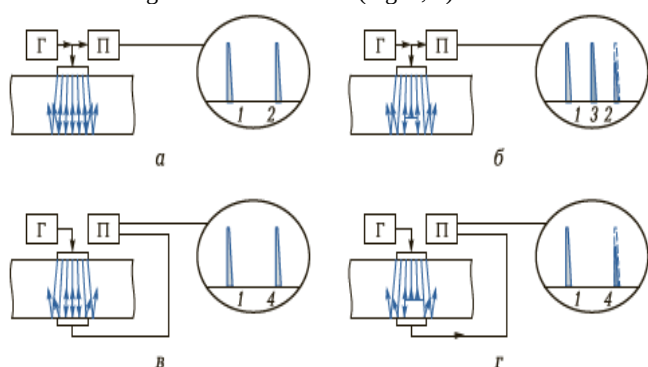


Fig. 1 Schemes of passage of short ultrasonic pulses with echo-pulse (a, b) and shadow (b, z) methods of testing welded joints:

a, b - in the absence of a defect, b, z - in the presence of a defect, 1 - short ultrasound pulse, 2, 3 - echo signals, 4 - signal with reduced amplitude, Г - probe pulse generator, П - receiver

When using it, a sign of the presence of defects is a decrease in the amplitude of signal 4 (Fig. 1, r)

The main advantages of ultrasonic flaw detection include the high sensitivity of the method, the mobility of the equipment, and the efficiency in obtaining results. The method is widely used in

industry to detect such defects as cracks, lack of penetration, slag and other inclusions in welded seams with a size of 1...28000 mm.

Formulation of the problem

Traditionally, ultrasonic testing of welded joints is carried out in the range from 0.5 to 10 MHz. Specialists can detect a large number of different defects, usually with sizes from units to tens of micrometers in metal products and whole building structures. In some cases, ultrasonic testing of welded seams is performed by pulses with a frequency of up to 20 MHz.

The main advantages of ultrasonic inspection:

- a) safety for personnel - ultrasonic waves, unlike X-rays, do not harm the person who is monitoring;
- b) the possibility of using the methodology at existing facilities, while they do not need to be decommissioned;
- c) mobility, modern ultrasonic flaw detectors are portable, they can be used where necessary, the devices do not take up much space and are relatively light in weight;
- d) no risk of damage to the investigated object - products are not destroyed during control;

The disadvantages of ultrasonic testing (especially when controlling products of microsystem technology) include:

- a) the impossibility of obtaining the exact dimensions of the defects. Defects of the same size and shape, filled with slag and air, are capable of reflecting pulses in different ways. Because of this, critical errors can occur during control;
- b) the complexity of the analysis of small parts of small (micrometric) thickness. Also, the procedure for controlling seams on objects of complex shapes with curved geometry becomes more complicated;
- c) the need for the preparation of metal surfaces - before control, it is necessary to clean products from organic and inorganic contaminants of various origins [3];
- d) the difficulty of studying metals with high grain size, as well as composite materials of complex structure. This is due to the structural features of such materials to "jam" ultrasound;
- e) the need to use a special contact compound in the controlled area to ensure optimal acoustic contact.

The microstructure of the weld and the heat-affected zone largely determines the properties of welded joints and characterizes their quality. Microstructure defects include the following: increased content of oxides and various non-metallic inclusions, micropores and microcracks, coarse grain, overheating, metal burnout, etc. [4].

Thus, there is a problem of determining microdefects in welding seams by the ultrasonic method in the technology of manufacturing microsystem equipment devices. Elimination of this problem by structural improvements of the high-precision method is currently not possible. Therefore, a rational solution to the problem of determining microdefects with high resolution in welded seams

of microsystem technology products is to carry out computer simulation of the ultrasonic process.

Solution to the problem

As you know, computer modeling is a method for solving the problem of analyzing or synthesizing a complex system based on the use of its computer model [5].

The authors proposed to create a dynamic computer model of the propagation of ultrasound in microwelded joints of metal samples in the presence of defects of various sizes and different origins. On the basis of this model, the determination of the regularity of the sensitivity of measuring a microdefect on the parameters of an ultrasonic microdefectoscope is carried out.

SimNDT software was used for simulation. The NDT ultrasonic simulator with a motor core based on the elastodynamic finite integration (EFIT) technique of solid media is designed to simulate the propagation of ultrasonic waves in a 2D homogeneous medium for viscoelastic and elastic materials.

A steel specimen 100x100 mm and the presence of many round defects with radii $R=2.5$ mm and 0.1 mm in it were considered. The filling material for defects is air. Ultrasonic testing was carried out at a frequency of 3 MHz using a direct ultrasonic transducer, Figs. 2, 3. A steel specimen 100x100 mm and the presence of many defects of various shapes, sizes and depths in it were also considered. The filling material for defects is water. Ultrasonic testing was carried out at a frequency of 3 MHz using a direct ultrasonic transducer, Fig. 2, 3.

Analyzing the results of computer simulation of ultrasonic scanning of microdefects of welded seams (Fig. 2 and 3), the following regularities of the accuracy of determining the location of microdefects, depending on their size, have been established.

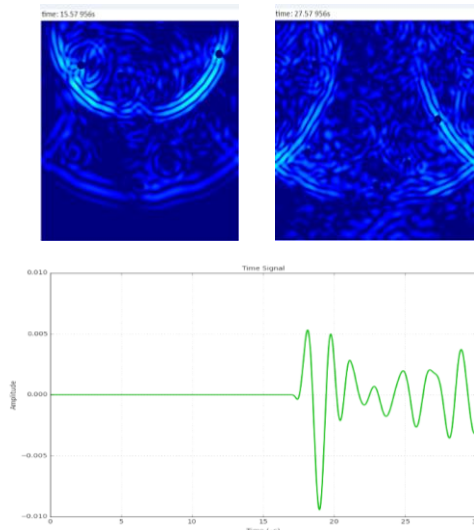


Fig. 2 Visualization of the process of propagation of ultrasonic waves (a) and the graph of the dependence of the amplitude on time (b) (defect size $R = 2.5$ mm and 0.1 mm)

So, in fig. 2 shows such a regularity for a spherical defect with a radius of $R = 2.5$ mm and 0.1 mm. As can be seen from the image of the visualization of the propagation of ultrasonic waves (Fig. 2), the defects have a distinct shape and location.

At the same time, visualization of the process of propagation of ultrasonic waves (Fig. 3) for defects of various shapes, sizes and depths of occurrence gives, in addition to the main image (corresponding to an excited signal, Fig. 3), an additional echo image. Such an echo image carries false information about the nature of the defects in ultrasound.

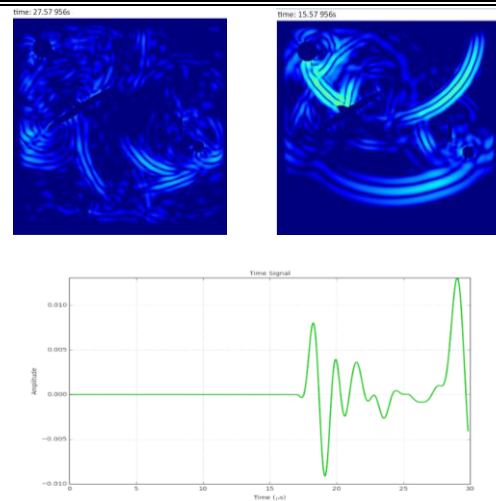


Fig. 3. Visualization of the process of propagation of ultrasonic waves (a) and the graph of the dependence of the amplitude on time (b) (defects of various shapes)

Conclusion

Thus, it has been shown that ultrasonic testing of welded seams allows, without destroying the weld itself, to identify such internal defects as: cracks, gas and slag inclusions, lack of penetration, etc.

The main disadvantages of methods for searching for microdefects in welded joints are established, including cumbersomeness, elongation in time, destructibility of the seam in the process of detecting a defect, the impossibility of accurately determining the depth of occurrence of defects, etc.

A dynamic computer model of the propagation of ultrasound in microwelded seams of metal samples in the presence of defects of various sizes in them is created, on the basis of which the regularities of the sensitivity of measuring such microdefects from the parameters of an ultrasonic microdefectoscope are revealed, showing the impossibility of determining microdefects with sizes less than 100 mm in welded seams of solid materials. This proves the need for a fundamental improvement of the ultrasound method, by means of the interference of acoustic ultrasonic waves of the main and echo signals at the assumed boundaries of defects, which makes it possible to increase the accuracy and resolution of determining the location of the shape and size of microdefects.

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Influence of the pressing force on the strength properties of sintered materials based on water-dispersed iron powders alloyed with copper

Ivanka Miteva, Ivan Mitev, Toschko Kovachev
Technical University Gabrovo, 14. Hadgi Dimitar Str. Bulgaria
idmiteva_prestij@abv.bg

Abstract: In this publication we study the influence of the pressing force on the strength characteristics of sintered materials based on water - dispersed iron powders alloyed with copper. Three brands of iron powders were studied - AHC 100.29, ASC 100.29 and ABC 100.30, to which 2 and 4% electrolytic copper were added. After pressing with a force of $300 \div 800$ MPa, they were sintered at a temperature of 1150°C for 1 h. Experiments were performed to determine three strength characteristics - tensile strength, yield strength, elongation. In determining the mechanical characteristics in order to prevent the influence of porosity, five measurements were made for each type of samples, and in the graphical interpretation of the results the arithmetic mean values were used.

Keywords: WATER DISPERSED IRON POWDER, COPPER, TENSILE STRENGTH, YIELD STRENGTH, RELATIVE ELONGATION

1. Introduction

Significant increase of the mechanical properties of the sintered materials with structural purpose is achieved by alloying the iron matrix with copper, nickel, chromium, molybdenum, tungsten and others elements. [2,3,4] Of the listed elements, copper is most often used for alloying structural sintered materials. At the sintering temperature it is in a liquid state [10,11,12] which helps to intensify the processes of coagulation of the pores, has a graphitizing effect, reduces the critical rate of hardening and thus increases the hardenability of the material and improves compressibility.

In ferro-copper alloys used in powder metallurgy, the concentration of copper varies in a relatively wide range - $0.5 \div 25\%$ [4,10,12].

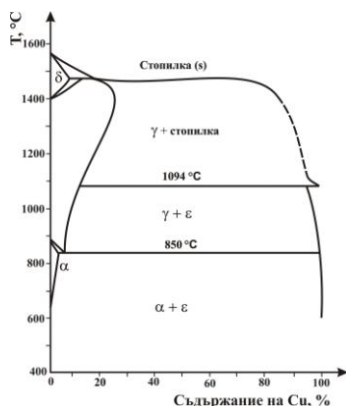


Fig.1. Diagram of the state of the iron-copper system [12]

Based on the state diagram of the binary system Fe-Cu - Fig.1, we can conclude that at such concentrations of copper in the iron matrix liquid phase in sintering the products can be realized only at temperatures higher than 1094°C . At this sintering temperature, up to 7.0% Cu can be dissolved in the Fe_γ lattice. At copper concentrations above these percentages, the two-phase mixture of copper-rich solid solution and Fe_γ is equilibrium.

It follows from the diagram that in case of pre-mixed iron and copper powders in arbitrary concentrations when heated above 1094°C , as a result of the formation of a liquid phase on the partition surface between the iron particles and copper there are conditions for sintering in the presence of liquid phase. After cooling, a significant amount of copper remains at low temperatures in the precipitated α solid solution and, with subsequent aging, leads to the strengthening of the alloys by the separation of the ϵ - phase.[12]

In the present study, the aim is to trace the influence of the pressing force and the concentration of copper on the strength characteristics of iron samples based on water-dispersed powders [6,8] type ANS 100.29, ASC 100.29 and ABC 100.30.

2. Experimental results

Three brands of iron powders were tested - ABC 100.30, AHC 100.29 and ASC 100.29. They are obtained by aqueous dispersion of a melt of iron scrub heated to temperatures of $16540 \div 1700^\circ\text{C}$. Nozzles with a diameter of $14 \div 16\text{mm}$ were used for spraying.

After spraying, the main technological properties of iron powders are determined, which are presented in Table №1.

Table 1: Technological properties of iron powders

Powder mark	Max. particle size, μm	Apparent density $\cdot 10^3\text{kg/m}^3$	Flowability, s	Compaction at 420MPa , $\cdot 10^3\text{kg/m}^3$	Max. O_2 , %	Max. C, %
AHC 100.29	170	2,98	25	6,91	0,10 0,20	0,01 0,02
ASC 100.29	170	2,98	25	6,82	0,10 0,15	0,01 0,02
ABC 100.30	170	3,00	25	6,75	0,10 0,15	0,01 0,02

The iron matrix of the tested samples was alloyed with 2 and 4% electrolyte copper with chemical composition according to table 2.

Table 2: Chemical composition of copper powder

Chemical composition, %			
Cu	O_2	H_2O	Fe
$99.5 \div 99.8$	$0.10 \div 0.30$	0,05	≤ 0.02
Pb	Sb	SO_4^{2-}	други
≤ 0.05	≤ 0.01	≤ 0.01	≤ 0.05

After homogenization of the powders, they are pressed with a force of $300 \div 800$ MPa. When pressing the samples to improve the compaction, 8% Lubricated PS plasticizer was added. [1,7] The samples thus formed were sintered at 1150°C in a dissociated ammonia medium for 1 hour.

The strength characteristics tests were performed according to EN 10045-1 on a universal testing machine ZD 40PU, with a range of applied force in the range of $100 \div 1000\text{kN}$. During the tests, specially made test bodies for powder metallurgical materials according to BDS 1086-88, with a rectangular cross section, with an area of 700mm^2 and basic dimensions according to Fig. 2 were used.[5,9]

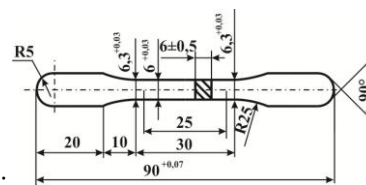


Fig.2. Drawing of a test tube of powder material to study tensile strength

In order to prevent the influence of the porosity in determining the strength characteristics, five measurements were made for each

type of samples, and the arithmetic mean values are plotted in the tables.

The experimental results in determining the tensile strength are presented in Table 3, and for the yield strength and elongation in Tables 4 and 5, respectively. For comparability of the experimental results, similar studies were performed in parallel on samples of pure iron.

The graphical interpretation of the results obtained in the experiments is presented in fig. 3 ÷ 11.

From the obtained experimental results it can be seen that for the samples of pure iron with small pressing forces - 300 ÷ 400 MPa the values for the tensile strength are of the order of 150 ÷ 170 MPa. As the pressing force increases as a result of the reduced porosity in the samples, their tensile strength increases by 40 ÷ 50%, reaching values of 220 ÷ 260 MPa. In this case, the change in the tensile strength values is only due to the reduced porosity, the increased surface contact between the particles and the increased density of the samples. This increase is most significant in samples of iron powder ANC100.29 - 56%, which is explained by their better formability compared to the other tested powders.

Table 3: Experimental results for tensile strength, MPa

Brand iron powder	Pressing force, MPa					
	300	400	500	600	700	800
	Tensile strength – Rm,MPa					
	100%Fe					
AHC 100.29	169	187	196	222	248	264
ASC 100.29	151	164	182	194	214	222
ABC 100.30	157	171	193	203	208	218
	Fe + 2,0%Cu					
AHC 100.29	196	212	233	241	275	284
ASC 100.29	218	231	264	278	286	298
ABC 100.30	207	227	251	278	284	299
	Fe + 4,0%Cu					
AHC 100.29	228	244	262	273	305	322
ASC 100.29	236	255	270	274	292	308
ABC 100.30	219	239	248	266	271	296

Table 4: Experimental results for yield strength, MPa

Brand iron powder	Pressing force, MPa					
	300	400	500	600	700	800
	Yield strength – Reh, MPa					
	100%Fe					
AHC 100.29	93	107	114	123	136	148
ASC 100.29	77	83	88	92	98	101
ABC 100.30	65	76	80	87	90	96
	Fe + 2.0%Cu					
AHC 100.29	158	171	179	188	195	209
ASC 100.29	162	178	195	217	219	231
ABC 100.30	154	164	171	176	196	202
	Fe + 4.0%Cu					
AHC 100.29	189	205	223	239	268	284
ASC 100.29	177	185	205	226	234	242
ABC 100.30	166	176	184	197	218	227

Table 5: Experimental results for relative elongation, %

Brand iron powder	Pressing force, MPa					
	300	400	500	600	700	800
	Relative elongation – ε, %					
	100%Fe					
AHC 100.29	8,10	9,30	10,42	11,67	12,97	14,74
ASC 100.29	9,94	12,38	15,38	17,87	18,44	19,43
ABC 100.30	17,21	18,35	20,15	21,54	22,02	22,13
	Fe + 2,0%Cu					
AHC 100.29	3,08	4,12	4,86	5,44	6,06	6,21
ASC 100.29	4,98	6,45	7,69	10,13	12,16	13,69
ABC 100.30	7,11	8,54	10,32	12,53	13,68	14,13
	Fe + 4,0%Cu					
AHC 100.29	1,03	1,78	1,84	1,97	2,04	2,15
ASC 100.29	1,87	3,14	4,05	4,86	4,96	5,87
ABC 100.30	3,72	4,56	5,04	5,17	5,98	6,57

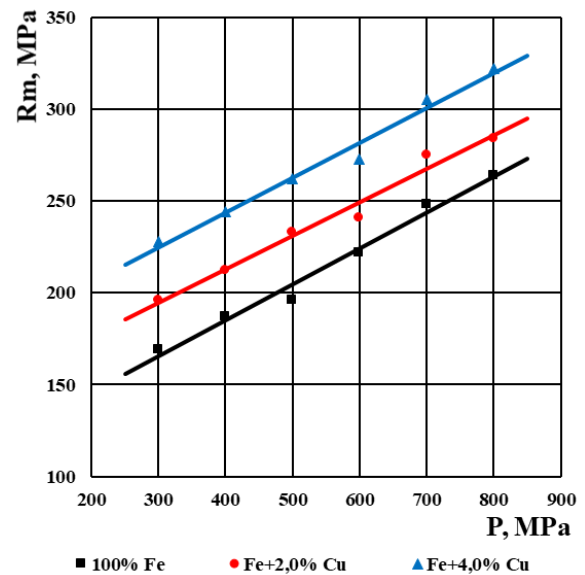


Fig. 3. Tensile strength for matrix specimens of iron powder AHC100.29

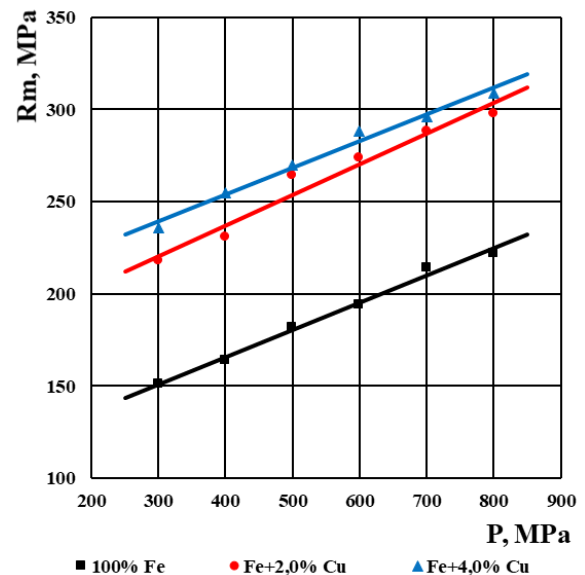


Fig. 4. Tensile strength for matrix specimens of iron powder ASC100.29

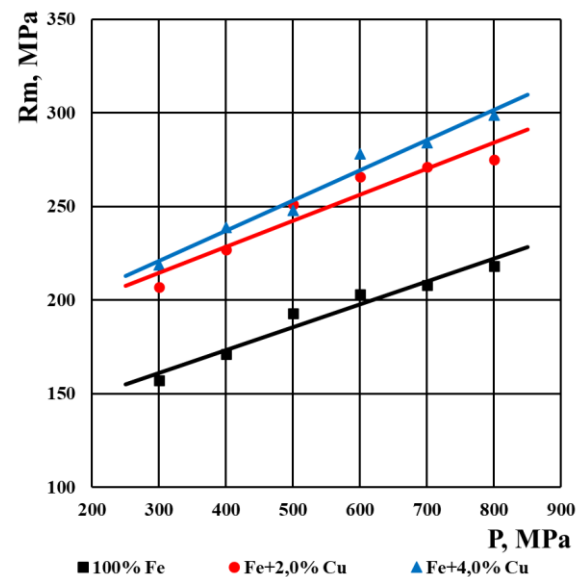


Fig. 5. Tensile strength for matrix specimens of iron powder ABC100.30

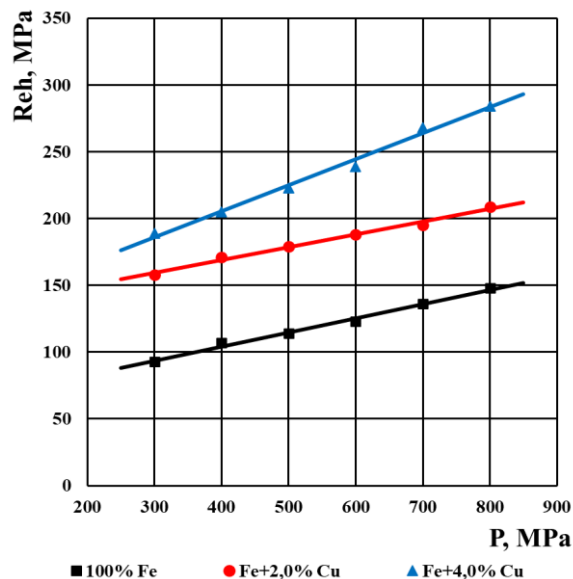


Fig. 6. Yield strength for samples with a matrix of iron powder AHC 100.29

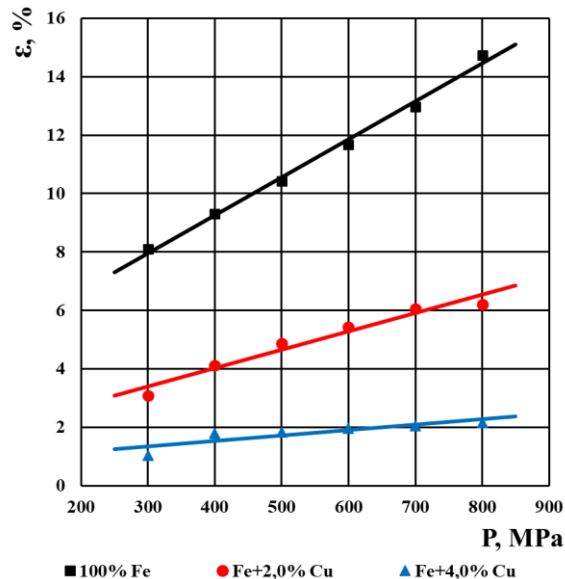


Fig. 9. Relative elongation for matrix samples of iron powder AHC 100.29

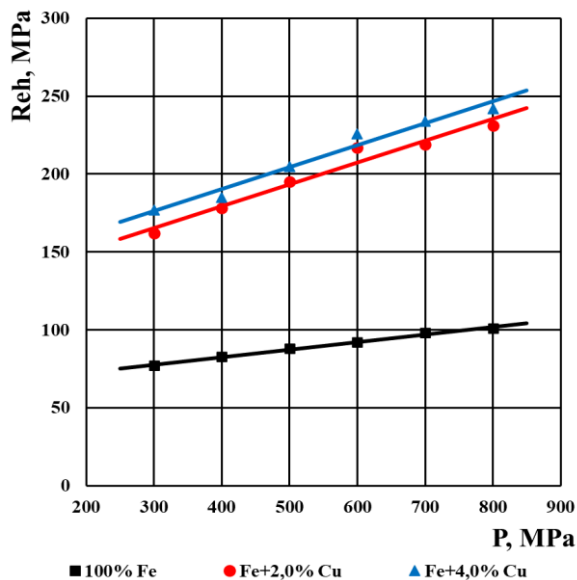


Fig. 7. Yield strength for samples with a matrix of iron powder ASC 100.29

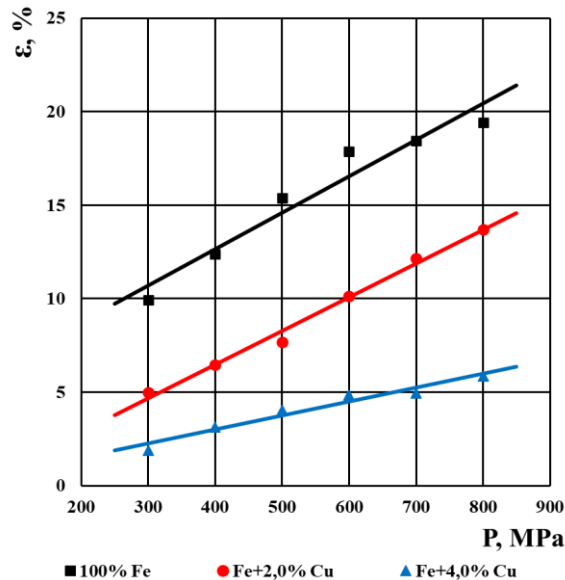


Fig. 10. Relative elongation for matrix samples of iron powder ASC 100.29

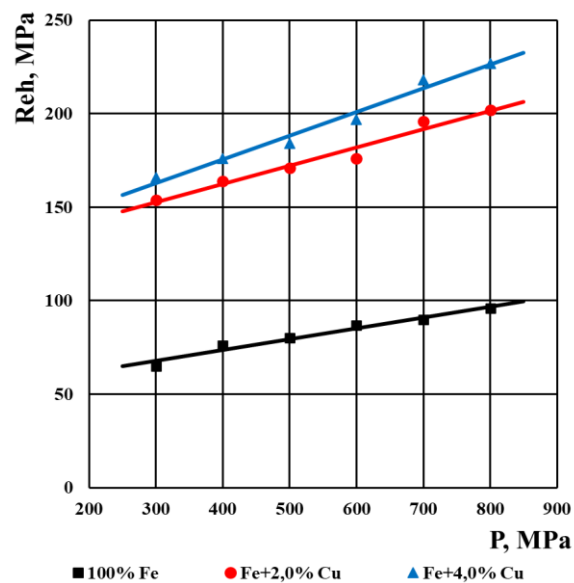


Fig. 8. Yield strength for samples with a matrix of iron powder ABC 100.30

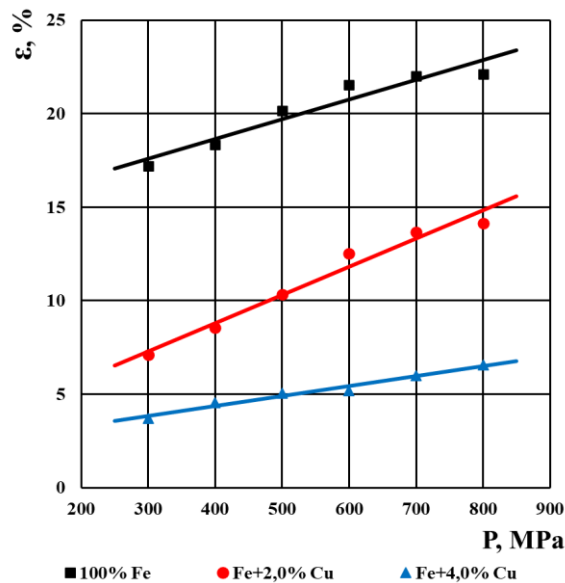


Fig. 11. Relative elongation for matrix samples of iron powder ABC 100.30

The addition of 2.0 ÷ 4.0% copper in the iron matrix allows at the sintering temperature - 1150°C, the process to be realized in the presence of a liquid phase in the iron matrix. This favors the coalition of the pores and leads to a significant change in the values of the closed porosity. This has a positive effect on the tensile strength after sintering, as its values increase by 60 ÷ 85 MPa regardless of the compression force. The highest values for the tensile strength are registered for samples alloyed with 4.0% copper.

The experimental results obtained in the study of the yield strength are similar. For samples of pure iron at low values of the pressing force, the results vary in a relatively narrow range of 65 ÷ 90 MPa. As the pressing force increases as a result of the reduced porosity, the values for the yield strength increase, as this increase is most significant in samples of iron powder ANC 100.29 - 55MPa, and in samples of iron powder ASC 100.29 and ABC 100.30 is respectively 25 and 30MPa. The addition of copper to the iron matrix leads to a significant increase in the values for the yield strength and despite the pressing force at a concentration of 4.0% copper in the iron matrix the values for the yield strength increase more than twice.

In structural details, the relative elongation is an essential mechanical characteristic that determines the behavior of the material, both in the process of operation and at different temperature influences. The changes in the values for the tensile strength and the yield strength registered above have a significant influence on the values for the relative elongation of the tested samples. From the obtained graphical dependences - fig.9 ÷ 11, it can be seen that they are highest in samples made of pure iron. They have a ferrite structure. Ferrite is a plastic phase, which allows the relative elongation to have high values. At low values of the pressing force 300 ÷ 400 MPa, depending on the type of iron powder, the relative elongation of the tested samples varies in the range of 10 ÷ 17%. The highest results are for samples of iron powder ABC 100.30 - 17%, and for other iron powders vary in the range of 8 ÷ 10%. As the pressing force increases to 800 MPa, the values for the relative elongation of the pure iron samples almost double and are of the order of 15 ÷ 22%. The addition of copper to the iron matrix increases the strength of the specimens, but this leads to a decrease in their relative elongation results. When pressing iron samples alloyed with 4.0% copper with a force of 300 ÷ 400 MPa, this decrease is 5 ÷ 8 times, and when pressing with a force of 800 MPa - 3 ÷ 7 times, the values varying respectively in the intervals 1.03 ÷ 3.72 % and 2.15 ÷ 6.55%.

3. Conclusion

The following more important conclusions can be formulated from the conducted researches and the obtained results:

✚It was confirmed that with increasing compressive force the density of the samples increases (decreases the amount of internal porosity) as a result of which the tensile strength and the yield strength of the samples of pure iron increases. This increase is most significant - 56%, in samples of iron powder ANC 100.29, which is explained by their better formability compared to iron powders type ASC 100.29 and ABC 100.30.

✚It has been confirmed that the addition of electrolytic copper to the iron matrix leads to the formation of a liquid phase in the sintering process at 1150 ° C. This accelerates the process of coalescence of the pores, reduces the relative porosity in the iron matrix and increases the tensile strength by 60 ÷ 85 MPa regardless of the compression force.

✚The highest values for the tensile strength, regardless of the type of iron powder used, are registered for samples alloyed with 4.0% copper and pressing force 800 MPa - 300 ÷ 320 MPa.

✚It was confirmed that the tensile strength is directly dependent on the yield strength of the samples. For samples of pure iron, regardless of the pressing force and the type of iron dust, the

values for the yield strength are 40 ÷ 55% of the values for the tensile strength. .

✚The addition of copper to the iron matrix improves the ductility of the samples. As a result, an increase in the values for the limit of proportionality is registered, as in samples alloyed with 4.0% copper they reach 75 ÷ 90% of the values for the tensile strength.

✚It was found that the values for the relative elongation are the highest in the samples of pure iron, as they have a pure ferritic structure and very high ductility. Depending on the pressing force, they vary in the range of 8.5 ÷ 22.0%, as the lower values are for samples pressed with a force of 300 MPa, and the higher values for samples pressed with a force of 800 MPa.

✚The addition of copper to the iron matrix has been shown to increase the strength of the specimens, but this leads to a decrease in their elongation results. When pressing iron samples alloyed with 4.0% copper with a force of 300 ÷ 400 MPa, this decrease is 5 ÷ 8 times, and when pressing with a force of 800 MPa - 3 ÷ 7 times, the values varying respectively in the intervals 1.03 ÷ 3.72 % and 2.15 ÷ 6.55%

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Preparation and study of new class SeO_2 based glass obtained at high oxygen pressure

Lyuben. Lakov, Stancho.Yordanov

Bulgarian Academy of Sciences, Institute of Metal Science, Equipment and Technologies with Hydro- and Aerodynamics Centre
 "Acad. A. Balevski", Sofia, Bulgaria¹,
 E-mail: stancho14@abv.bg

Abstract: In recent years, scientists have turned their attention to the synthesis of a new class of amorphous materials – glass with the participation of SeO_2 (selenite glass), and to the study of their structure. Among the established centers for systematic research on these materials are the Institute of Metal Science, Equipment and Technologies with Center for Hydro- and Aerodynamics "Acad. A. Balevski" at the Bulgarian Academy of Sciences (IMSETHC – BAS) – Sofia, Bulgaria and the Department of Silicate Technology at the University of Chemical Technology and Metallurgy (UCTM) – Sofia, Bulgaria. These types of glass have specific properties such as high permeability in the visible and the near infrared regions of the spectrum, high refractive index, and low melting point. On the other hand, the amorphous materials in this class of can serve as model compositions. The obtained structural information can be used to form generalizations about the vitreous state and the possibility to modify the structure and properties of glass in order to improve the technological parameters.

Keywords: SeO_2 (selenite glasses)

1. Introduction

The amorphous state offers great opportunities for creating new useful materials with various applications, so in the leading laboratories around the world more and more new types of glass are being synthesized and studied: oxide, halide, chalcogenide, metal, etc. Thanks to modern methods of production and research, many new materials are currently being studied, including various types of glass [1-22].

This monograph presents new phase diagrams and shows the way they are obtained and analyzed. It further deals with the study of the structure and the glass formation of bicomponent and multicomponent glass with the participation of SeO_2 , synthesized at high oxygen pressures and slow cooling rate. The monograph aims to confirm the tradition of researching these types of glass in Bulgaria, which is the unique place in the world where they have been successfully obtained at high pressures without sublimation and under reproducible experimental conditions.

The compositions of the mixtures required for the research are prepared in the conventional way. The components introduced are purity grade oxides. The weighing and preparation of the mixtures is performed in a box chamber. Melting is carried out in accordance with the research mode and in quantities depending on the type of the study.

When building the phase diagrams, the charges are placed in vacuumed and soldered quartz ampoules at $P = 0.1$ Pa. The ampoules thus prepared with a volume of $V = 2 \text{ cm}^3$ and a weight of the charge in them of 1 g are subjected to tests to determine the phases in order to build the phase diagrams.

When determining the areas of glass formation, the charges are placed in an autoclave installation in test tubes made of quartz glass or Razotherm®. The maximum pressure during the heat treatment process is the same for all – 35 MPa in an oxygen environment. The compositions are melted at a maximum temperature of 823.15 K, which is reached in 2 hours and maintained for 20 minutes. The samples are then cooled at a rate of 2 K/min.

2. Experimental

2.1. Method for synthesis of sublimating oxides, including glass with the participation of SeO_2 (selenite glass)

Experimental studies of the processes of melting and glass formation in systems containing sublimating or dissociating components are few in number [29-31]. This is explained by the technological difficulties that exist in the simultaneous combination of high pressure and high temperature in the presence of volatile substances. At the same time, it should be noted that in the course of experimental practice considerable experience has been gained in the use of various installations operating at elevated gas pressures. When working with highly volatile substances (such as SeO_2), two methods of synthesis are used: in pressure vessels and in vacuumed and soldered quartz ampoules. The most suitable ones in this

particular case are various types of autoclaves, in which both the oxygen pressure and the redox conditions in the system can be controlled across a wide range.

The main element of the autoclave is the reaction chamber. It can be heated both indirectly and with a furnace built into it.

Generation of gas pressure is done using different one-stage and two-stage compressing installations, or simply, in steel cylindrical vessels filled with the respective gas selected for the specific purpose.

The vessel in which the pressure is created is subjected to the greatest loads. Structurally, cylindrical vessels are the most suitable ones due to the lowest stress strain upon them when heated under pressure. The samples are placed in a vessel that does not interact with the test material and with the gaseous medium.

The other units constituting an autoclave installation are: housing, heaters, thermal insulation, thermocouples and temperature and pressure measuring devices. Figure 1 shows the diagram of an autoclave.

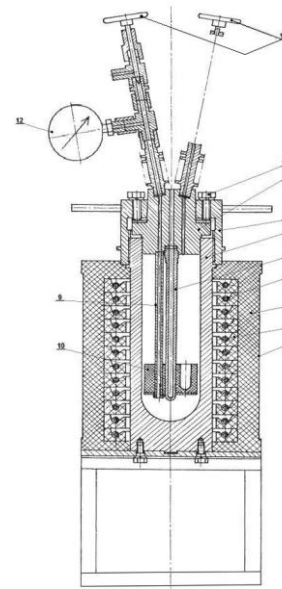


Figure 1. Diagram of an autoclave working at maximum pressure $P_{\max} = 50 \text{ MPa}$ and maximum temperature $T_{\max} = 600^\circ\text{C}$ (873.15 K)

Description of the units that make up the autoclave installation:

1. Housing.
2. Thermal insulation.
3. Ceramic bearers of the heaters.
4. Heaters (made of Kanthal A1).
5. Body.

6. Pressure lid.
7. Steel plug – sealing “metal to metal”.
8. Metal cover of the thermocouple.
9. Gas (oxygen) supplying tube to which is mounted the refractory ceramic base for the samples.
10. Refractory ceramic base for the samples.
11. Valves sealing “metal to metal” – the gas inlet and outlet of the steel sealing plug.
12. Pressure gauge for pressure up to $P_{\max} = 50$ MPa.
13. Bolts fixing the steel plug.

The pressure in the autoclave is measured using a manometer with a scale of up to 100 MPa. On the outside of the cylindrical autoclave body is installed a resistance heating furnace with an operating temperature of up to 973.15 K. Reaching the required operating temperature is done by heating the entire two-liter volume of the reaction chamber. An additional refractory ceramic base 10 is mounted inside the autoclave by means of a hollow bolt attaching it to the gas supplying tube 9. In the ceramic base 10 are nested quartz glass test tubes used to study the synthesis of small amounts of selenite glass. Quartz glass turned out to be a suitable material for the test tubes, as no corrosion on its surface caused by the studied melts was observed. When the aim was to obtain large quantities of melt, single quartz crucibles or Rasotherm® vessels were used.

The installation works as follows:

Before heating, the reaction chamber of the autoclave is filled with gas from a bottle up to a pressure of 11 MPa using a valve. In order to perform the experiments in dry conditions before filling the autoclave, the gas is passed through another vessel filled with magnesium perchlorate which adsorbs the moisture. Oxygen is used as a gaseous medium to transfer pressure to the charges containing SeO_2 , thereby maintaining oxidation conditions. When other gaseous carriers are used, the experiments can also be performed in neutral and reducing mediums for the synthesis of glass and other materials at high pressures up to 50 MPa and temperature $T = 873$ K.

When preparing the charges, all the compositions studied in the monograph are expressed in mole percentages. They are presented as numerical indices for each oxide participating in a given composition.

Any mass loss during the experiments possibly caused by sublimation and evaporation was controlled using a weight method. It was found that the mass loss after melting does not exceed 1 – 1.5%.

Another safe method that can be applied for synthesizing selenite glass is melting in vacuumed and soldered ampoules of quartz glass. This method has some limitations when synthesizing larger amounts of material. It is used mainly when performing DTA (differential thermal analysis) and X-ray diffraction analysis.

The pressure in the ampoule is reduced using a vacuum pump before soldering. Thus, during the melting process the pressure above the initial mixture is created by the vapor of the components in the mixture, which in fact provides the necessary conditions for melting under pressure.

The problem of studying vitreous pressure systems has not been the subject of detailed research, as from a practical point of view this is not a strict requirement when producing traditional glass. However, when developing methods for synthesizing glass containing sublimating and dissociating components, the creation and control of a sufficient high pressure is fundamental.

The preliminary studies on glass with the participation of SeO_2 showed that at temperatures up to 873.15 K, experiments should be conducted in a closed system (autoclave) with the ability to create an operating pressure of tens of MPa (initial pressure of 35 MPa), which practically prevents sublimation.

The methodology developed for the study of glass formation at elevated oxygen pressure aims to prevent the decomposition of the samples and to minimize changes in the initial composition. In addition, the pressure affects the tendency for glazing, the structure of the glass and some technological parameters in the transformation interval.

It should be emphasized that many of the compounds are extremely toxic. This requires that when working with selenium, selenium dioxide, selenites, selenates, etc. protective equipment should be used. In addition, high-pressure research also requires precautions regarding the danger of explosions, burns, etc.

All compositions in the studies were prepared in the same way. The components were introduced into the charge as purity grade oxides. They were weighed and prepared in a box chamber. When determining the areas of glass formation of the samples placed in the autoclave installation, the melting was carried out, as indicated, in quartz tubes in quantities of about 5 grams. The maximum pressure during the experiment for all compositions was the same – 35 MPa in an oxygen environment. The compositions were melted at a maximum temperature of 823.15 K, which was reached within 2 hours and maintained for 20 minutes. The samples were then cooled at a rate of 275.15 K / min.

The research results presented in the monograph are as follows:

- New 4-phase diagrams of the systems $\text{SeO}_2\text{-TeO}_2$, $\text{SeO}_2\text{-MoO}_3$, $\text{SeO}_2\text{-Bi}_2\text{O}_3$, and $\text{SeO}_2\text{-V}_2\text{O}_5$ are built;
- The areas of glass formation in binary, triple and four-component systems with the participation of SeO_2 , TeO_2 , MoO_3 , Bi_2O_3 and V_2O_5 are determined;
- Shown are the methods of study of the new phase diagrams, the glass formation and the structure of the obtained glass, through which the main structural units and properties are determined. They are:

- Differential thermal analysis (DTA);
- Infrared spectroscopy;
- Photoelectron spectroscopy;
- Neutron diffraction;
- Optical spectra in the visible and infrared range.

The research using the modern methods of analysis shows that:

1. The built new phase diagram of the system $\text{SeO}_2\text{-MoO}_3$ is of simple eutectic type. The composition of the eutecticum is about 90 mol % SeO_2 , and the corresponding eutectic temperature is $250^\circ\text{C} \pm 5^\circ\text{C}$. Using infrared spectroscopy, the types of structural units that make up the network of glass in the binary system $\text{SeO}_2\text{-MoO}_3$ are determined. It is shown that the network is transformed by varying the composition. Layers containing MoO_6 groups in which SeO_3 units are embedded are torn and converted into molybdate complexes Mo_2O_8 , included in a continuous chain structure containing SeO_3 groups with the formation of isolated Se=O bonds.
2. The phase diagram of the system $\text{SeO}_2\text{-Bi}_2\text{O}_3$ in the region 100 - 50% SeO_2 is built, with a eutecticum at about 90 mol % SeO_2 . The existence of the Bi_2SeO_5 , $\text{Bi}_2\text{Se}_4\text{O}_{11}$ and $\text{Bi}_2\text{Se}_3\text{O}_9$ is confirmed and the peritectic decomposition temperatures of the compounds $\text{Bi}_2\text{Se}_4\text{O}_{11}$ and $\text{Bi}_2\text{Se}_3\text{O}_9$ are established. It is shown that intake of more than 20% Bi_2O_3 dramatically increases liquidity temperature.
3. Part of the phase diagram of the system $\text{SeO}_2\text{-TeO}_2$ /50% SeO_2 is constructed. The new phase with composition $\text{SeO}_2\text{-TeO}_2 = 1:1$ forms a eutecticum with SeO_2 at 75% SeO_2 . The character of the liquid line, built on the data from the DTA analysis, shows that based on its method of melting, the compound can be defined as lying at the boundary between congruent and incongruent.
4. Based on the conducted research, the most probable type of the phase diagram $\text{SeO}_2\text{-V}_2\text{O}_5$ is built. The existence of the $2\text{Se}_2\text{V}_2\text{O}_5$ phase is confirmed.
5. For the first time, the glass formation in 35 two-component systems based on SeO_2 is studied, and in 14 of them the boundaries of the glass formation areas with stable selenite glass are established with the participation of: B_2O_3 , In_2O_3 , Sc_2O_3 , Y_2O_3 , La_2O_3 , Pr_2O_3 , Nd_2O_3 , MgO , PbO , Sb_2O_3 , Bi_2O_3 , V_2O_5 , TeO_2 and MoO_3 . The process of glass formation (melting and cooling) has been carried out in an autoclave system at an oxygen pressure of 35 MPa and a maximum temperature of 823.15 K with subsequent cooling at a rate of 2 K/min.
6. The areas of glass formation in 35 three-component selenite systems in which besides SeO_2 the main network-forming components are MoO_3 , Bi_2O_3 , V_2O_5 and TeO_2 are studied and determined;

Based on the binary system $\text{SeO}_2\text{-TeO}_2$, the glass formation in: $\text{SeO}_2\text{-TeO}_2\text{-V}_2\text{O}_5$, $\text{SeO}_2\text{-TeO}_2\text{-Sb}_2\text{O}_3$, $\text{SeO}_2\text{-TeO}_2\text{-MoO}_3$, $\text{SeO}_2\text{-TeO}_2\text{-Nb}_2\text{O}_5$, $\text{SeO}_2\text{-TeO}_2\text{-La}_2\text{O}_3$, $\text{SeO}_2\text{-TeO}_2\text{-B}_2\text{O}_3$, $\text{SeO}_2\text{-TeO}_2\text{-Nd}_2\text{O}_3$ is determined.

Based on the binary system $\text{SeO}_2\text{-MoO}_3$ the glass formation in: $\text{SeO}_2\text{-MoO}_3\text{-CuO}$, $\text{SeO}_2\text{-MoO}_3\text{-MgO}$, $\text{SeO}_2\text{-MoO}_3\text{-CoO}$, $\text{SeO}_2\text{-MoO}_3\text{-NiO}$, $\text{SeO}_2\text{-MoO}_3\text{-Pr}_2\text{O}_3$, $\text{SeO}_2\text{-MoO}_3\text{-Sc}_2\text{O}_3$, $\text{SeO}_2\text{-MoO}_3\text{-Bi}_2\text{O}_3$, $\text{SeO}_2\text{-MoO}_3\text{-Sb}_2\text{O}_3$, $\text{SeO}_2\text{-MoO}_3\text{-B}_2\text{O}_3$, $\text{SeO}_2\text{-MoO}_3\text{-Nd}_2\text{O}_3$, $\text{SeO}_2\text{-MoO}_3\text{-La}_2\text{O}_3$, $\text{SeO}_2\text{-MoO}_3\text{-Nb}_2\text{O}_5$ is determined.

Based on the binary system $\text{SeO}_2\text{-Bi}_2\text{O}_3$, the glass formation in: $\text{SeO}_2\text{-Bi}_2\text{O}_3\text{-NiO}$, $\text{SeO}_2\text{-Bi}_2\text{O}_3\text{-Sb}_2\text{O}_3$, $\text{SeO}_2\text{-Bi}_2\text{O}_3\text{-Nd}_2\text{O}_3$, $\text{SeO}_2\text{-Bi}_2\text{O}_3\text{-Nb}_2\text{O}_5$, $\text{SeO}_2\text{-Bi}_2\text{O}_3\text{-V}_2\text{O}_5$, $\text{SeO}_2\text{-Bi}_2\text{O}_3\text{-Ga}_2\text{O}_3$, $\text{SeO}_2\text{-Bi}_2\text{O}_3\text{-WO}_3$, $\text{SeO}_2\text{-Bi}_2\text{O}_3\text{-La}_2\text{O}_3$, $\text{SeO}_2\text{-Bi}_2\text{O}_3\text{-SnO}_2$, $\text{SeO}_2\text{-Bi}_2\text{O}_3\text{-MgO}$, $\text{SeO}_2\text{-Bi}_2\text{O}_3\text{-Pr}_2\text{O}_3$, $\text{SeO}_2\text{-Bi}_2\text{O}_3\text{-Sc}_2\text{O}_3$ is determined.

Based on the binary system $\text{SeO}_2\text{-V}_2\text{O}_5$ the glass formation in: $\text{SeO}_2\text{-V}_2\text{O}_5\text{-B}_2\text{O}_3$, $\text{SeO}_2\text{-V}_2\text{O}_5\text{-Sb}_2\text{O}_3$, $\text{SeO}_2\text{-V}_2\text{O}_5\text{-Nd}_2\text{O}_3$ и $\text{SeO}_2\text{-V}_2\text{O}_5\text{-BaO}$ is determined.

By comparing the regions of glass formation in the three-component systems, the empirical conclusion is made that the participation of MoO_3 in selenite systems provokes the formation of broader regions in comparison with those with the participation of Bi_2O_3 and V_2O_5 .

7. The areas of glass formation in the following 4 four-component systems are studied and phase diagrams are built: $\text{SeO}_2\text{-MoO}_3\text{-V}_2\text{O}_5\text{-TeO}_2$, $\text{SeO}_2\text{-MoO}_3\text{-V}_2\text{O}_5\text{-Bi}_2\text{O}_3$, $\text{SeO}_2\text{-MoO}_3\text{-V}_2\text{O}_5\text{-B}_2\text{O}_3$ and $\text{SeO}_2\text{-MoO}_3\text{-Bi}_2\text{O}_3\text{-Sc}_2\text{O}_3$. The widest area is synthesized in the four-component system $\text{SeO}_2\text{-MoO}_3\text{-V}_2\text{O}_5\text{-B}_2\text{O}_3$.

8. The study of three- and four-component glass with the participation of SeO_2 by means of infrared spectroscopy shows that the network of multi-component glass is composed mainly of SeO_3 , Mo_2O_8 , VO_5 and BiO_6 groups. It is proved that the formation of strong bridge ties is a priority for glass formation in selenite systems, which confirms one of the basic principles of Zachariasen.

9. The functions of radial distribution of glass by means of neutron diffraction from the systems: $\text{SeO}_2\text{-MoO}_3\text{-Bi}_2\text{O}_3$, $\text{SeO}_2\text{-MoO}_3$, $\text{SeO}_2\text{-MoO}_3\text{-CuO}$ и $\text{SeO}_2\text{-V}_2\text{O}_5\text{-Sb}_2\text{O}_3$ are determined. It is confirmed that SeO_2 participates as SeO_3 groups in the glass network.

10. Based on photoelectron spectroscopy, it is found that in selenite glass the degree of oxidation of Se is Se (IV). When melting in an autoclave, the oxides that participate in the selenite glass retain their specified degree of oxidation.

11. The optical properties of selected glass compositions are studied. Green-colored glass with Pr_2O_3 and yellow-colored with Bi_2O_3 and Sc_2O_3 are obtained, which are permeable from 400nm to 2,200nm. The influence of water molecules and OH groups on permeability is established. The width of the optical band gap is determined.

12. The conducted model studies of the systems $\text{SeO}_2\text{-MoO}_3$, $\text{SeO}_2\text{-Bi}_2\text{O}_3$, $\text{SeO}_2\text{-V}_2\text{O}_5$, $\text{SeO}_2\text{-TeO}_2$, and the data for glass formation in the multicomponent selenite systems, can be used to predict compositions of selenite glass of practical interest – ones that are stable relative to crystallization and have low hygroscopicity and low melting point.

13. On the basis of the research and related to the monograph (protected by intellectual property rights), the research team led by Prof. Lakov has 6 /six/ patents for [23-28]:

1. Glass for yellow light filter
2. Glass for orange light filter
3. Glass for red light filter
4. Glass for black light filter
5. Red glass
6. Black glass

3. Conclusions

In the existing literature on the subject, there is no evidence that SeO_2 is a major glass-forming factor. The present monograph and the numerous citations prove that SeO_2 produces glass at high oxygen pressure of 35 MPa (to prevent sublimation of SeO_2) and subsequently at unusually slow cooling rate of 2K/min. This suggests that SeO_2 is the main glass-forming factor, which

complements the basic hypotheses concerning glass, as well as Feltz's scheme for different cooling rates of glass forming melts.

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