Fixed joints applied in car construction

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Abstract: *The paper deals with the problem of joints of car parts of the car construction. The construction of the car must meet the emission standards, in order to meet them it is necessary to reduce the weight of the car while maintaining strength and durability. Therefore, different materials are used in the design of car construction, such as different types of steels, aluminum alloys, composites and plastics. This increases the demands on the car construction and on the type of sheet metal joining technology used. The paper deals mainly with glued and welded joints in the design of car construction. The suitability of individual types of joints is solved using the finite element method.*
Keywords*: FIXED JOINTS, FEM, AUTOMOTIVE INDUSTRY, CONSTRUCTION*

1. Introduction

Reducing car body weight is one of the main goals in car body design. Demands for CO2 emissions are constantly increasing, and more expensive fossil fuels require a reduction in fuel consumption. The effort of designers in the automotive industry is to use a material that would meet the lowest possible weight without compromising the safety of the crew, ideally with the lowest possible production costs [1]. We do not encounter such a variety of materials used for car body construction anywhere else in any mass-produced engineering product.

The construction of a car is made up mostly by steel of various qualities and properties. Steel makes up more than 80% of a car's construction. Thanks to its properties, steel is a suitable material for car bodies construction, and thanks to its low price (compared to other suitable materials), it is also the most used material. Recently, extremely strong steel is also used - this type of steel differs from the others in that it is not made to achieve a specific chemical composition, but to achieve certain properties [2].

The average weight of road motor vehicles has been declining since the 1970s. The average European vehicle weighs almost 1,100 kg, with ferrous metals (60%), non-ferrous metals in particular aluminum (7%), plastics (10%), rubber (4.5%), glass (3%), textiles and anti-noise mass (4%), paint and putty (1.5%), liquids and other materials (7%). The material currently represents 30% of the production cost, so there is a great effort by manufacturers to reduce its consumption. A favorable argument for the use of plastics in car production is the recyclability of all thermoplastics.

The use of plastics is also associated with innovations that are intended to increase safety, comfort and increase environmental friendliness. At present and also in the near future, the use of special composite reinforcement materials in car bumpers is expected, which show three times higher rigidity and energy absorption than ordinary plastic. Plastic headrests contribute to greater passenger safety. In the event of a kickback, the front half of the headrest moves forward as a result of activation, reducing the risk of personal injury in the car. The main use of new materials or existing materials by replacing e.g., metals require a number of tests and experiments of their effective and efficient use. New trends in car development are focused on the use of new, lightweight or composite materials, for special surface treatments of car bodies, the use of light metal structures as well as for increasing the share of plastics for the assembly of modern types of cars. From the production-technical point of view, plastic composites filled with natural fibers of flax, cotton or sisal proved to be the best. By using these composites, great profile stability of the manufactured parts, their good impact safety, minimal emissions in the interior and high dimensional freedom are achieved.

Time plays an important role in car construction. Therefore, the aim is to use the most effective - the fastest ways of joining materials in the production of automotive parts, or in the construction of the entire car body [3]. However, the speed of joining materials and welding must not increase at the expense of the quality of joints and welds.

2. Joining materials in the automotive industry

In the automotive industry, it is necessary to combine materials of various qualities and thicknesses, whether plated or unplated, but also ferrous and non-ferrous metals. Thus, in addition to traditional steel, wider use is given to aluminum, carbon, magnesium, high-strength steel and also plastics. With conventional methods of connecting materials, such as spot resistance welding or laser welding, it is not always possible to ensure the required quality of joints. That is why companies are exploring alternative methods of joining materials.

Conventional methods of joining materials in the automotive industry include welding, laser welding, soldering, and gluing.

Welding technology is mainly associated with metallic materials. However, there are also polymeric composite materials (thermoplastic matrix composites) that can be connected by this technology. The advantages of welding are good mechanical properties and resistance of joints, short processing time and minimal need to prepare connected surfaces. The main disadvantages of this type of connection for composite materials are the restriction exclusively to thermoplastic materials, problems with the disassembly of connected parts and the presence of foreign substances in the structures of materials needed for individual types of welding (induction, resistance, ultrasonic). Laser welding is also increasingly used in the automotive industry (Fig. 1).

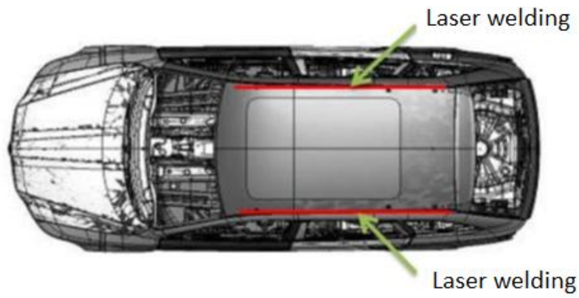

Fig. 1 *Laser connection on the roof of the car.*

At present, car body plates are most often joined by resistance (spot, seam and projection) welding technology. This technology has several disadvantages. These disadvantages include, for example, problematic joining of sheets of different thicknesses and qualities, or thermal influencing of the welded area. Other specific problems are caused by the zinc coating, which serves as a corrosion protection in cars [4]. Zinc adheres to the electrodes and there is a problem at the weld seams to maintain the protective function of the coating.

Mechanical connecting is the most widely used method of connecting materials. However, it has many disadvantages. These disadvantages are, for example, the increase in the weight of the structures due to the need to enlarge the joints, the stress concentration at the joints, the risk of galvanic corrosion (especially in the case of CFRP), the possibility of delamination in the production of holes, differences in thermal expansion of different types of joined materials. The main advantages of this type of material connections include the possibility of disassembly of the connected parts.

Glued joints appear in the automotive industry in many types, both in terms of functional stress and in terms of design. It can be said that the bonding either acts as a complementary and sealing function (bonding and cementing of bodies for sealing, vibration damping, corrosion protection, application of reinforcements) or, in specific cases, can generally represent welding technology in structural strength joints [5]. Some applications of glued joints can be seen in Figure 2.

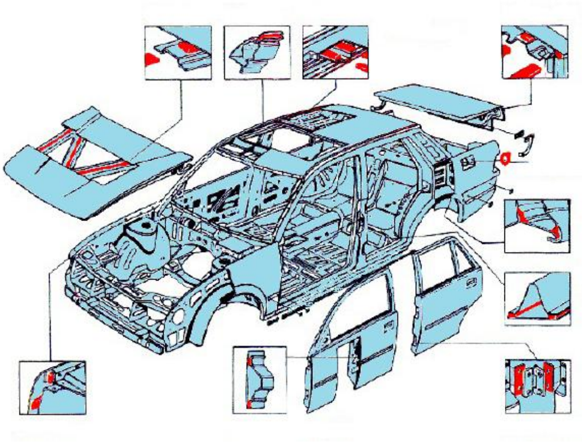

Fig. 2 *Glued joints of the car body [6].*

By using the bonding technology we avoid these problems and we can take advantage of the many advantages it offers in the automotive industry. Such as the possibility of new assembly procedures, reduction of the resulting weight of the car, preservation of the protective layer of zinc, higher strength and rigidity of the body, high quality of appearance of the parts to be joined and substantial reduction of noise in the car body.

It also has number of complications with the use of bonding technology in car body construction. For example, the adhesive must be overpainted, due to production, short time intervals to cure the joint, the adhesive life must be longer than that of a car, the adhesive must have sufficient strength, the shrinkage of the adhesive during curing on the car body surface.

The nature and composition of the adhesives used to build the car body is always firmly linked to the desired function of the joint. In this way, the adhesives can be divided into strength, reinforcement and sealing. Strength adhesives cure together with body paint. The edge adhesives are partially cured by induction heating during assembly, but full hardness is achieved only during the curing of the varnish by high temperatures in the furnace. The designer currently has a choice of many types of adhesives with different mechanical properties, ranging from tensile to brittle behavior. In the automotive industry, we are particularly interested in strength adhesives.

3. Use of FEM in the calculation of glued joints

Recently, at ever faster evolving computer technology and available literature, we can encounter modern numerical methods, such as finite element method (FEM). It is one of the most widespread numerical mathematical methods used to solve the problems of elasticity and strength, the dynamics of pliable bodies, heat transfer, fluid flow, electromagnetism, and many other problems in engineering.

Knowledge of the behavior of glued joints is essential for their subsequent application in practice. For effective prediction of the properties of glued joints it is necessary to use suitable tools allowing to accurately model various modes of failure that may occur in the structure. The failure of glued joints includes the area from the beginning of loading to the initiation of the crack, followed by the area of development of the failure.

The possibility of numerical simulation of the glued joint is the main requirement for its successful design. If a suitable numerical method was found, it would be possible to replace a large part of the glued joint experiments with this simulation. This would lead to a reduction in the times involved in the development, production and production cost of the product. The simpler tools offered by FEM analysis allow you to model only the area from the beginning of the load to the initiation of damage. The principles of linear elastic fracture mechanics apply in this area. The behavior in this area is described by the cohesive stiffness of the adhesive layer. The failure initiation state occurs at a critical value of the stress at the crack front. In the FEM model, this state describes the tension between the nodes of an idealized adhesive layer caused by their critical displacement and critical load.

In addition to the strength approach, advanced analyzes can also be based on the elasto-plastic fracture mechanics approach to describe the area of failure development. These principles apply especially in a situation where the adhesive layer is very thin between two parts to be glued and its behavior cannot be described by macroscopic properties, such as tensile modulus or Poisson's constant (E, ν) [5]. In these cases, the behavior of the bonded joint by the energy required for crack propagation, or the rate of release of the strain energy G, is described. These approaches make it possible to predict the onset and spread of failure without prior knowledge of the location of the crack and the direction of crack propagation in the structure. The quality of the calculation and the accuracy of the results are directly dependent on how ideally the adhesive layer can be idealized using conventional and advanced tools offered by FEM analysis [7]. In addition to the accuracy of the results, the duration of the calculation, these can also differ in the user-friendliness of the results.

Elements commonly available in FEM analyzes can be used to idealize the adhesive layer. Their behavior is described in terms of material parameters, which in some cases can be obtained from glue producers, but more often it is necessary to find out more difficult by means of experiments. Specifically, the adhesive layer can be replaced by contact, 3D elements, 2D elements, a linear spring system, or simply replacing the adhesive, such as the SSG element in Siemens NX or the TIE element in Abaqus.

The first step is to create a CAD model. This model is then converted into a preprocessor, which converts the geometric model into the form necessary for the calculation itself. In this phase, the main task is to create an adequate computer network and to define the initial conditions correctly. The preparation of the whole calculation model follows the rules that each company creates itself and must be strictly observed. The rules are set to achieve a compromise between computational complexity and result accuracy.

The next step is to load the file into the solver and start the calculation itself. The calculation is started using the command line and follows the mathematical operations described above. The results are written to files during the calculation.

The last step is to load and process the results in the postprocessor. The postprocessor allows viewing the simulated process, plotting acceleration, stress, strain and many other variables depending on the selected variable.

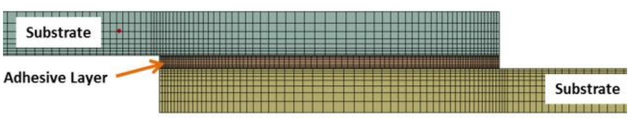

Fig. 3 *2D plain strain finite element model of bonded joint.*

In recent years, models using the so-called cohesive joint model have been used in the research of glued joints. The cohesive Model can be used to model adhesives, bonded surfaces, seal models, patches, or delamination processes (Fig. 3). The cohesive model exploits some of the advantages of common FEM elements and is based on Griffith's refraction theory. The aforementioned common elements included in the FEM creation tools are characterized by the absence of a criterion for predicting the evolution of violations for any violation mode. The cohesive model is innovative and used approach for the calculation and prediction of the evolution of bonding failure, specifically this model includes, compared to the previously mentioned models, the area of crack initiation in the structure.

The cohesive model must be implemented in the numerical model of FEM analysis. All elements making it possible to apply the principles of the cohesive model are generally referred to in the literature as decohesive elements. These elements can be one-dimensional, two-dimensional, and three-dimensional elements and include commonly available solver for FEM analysis. Cohesive elements are used for modeling an adhesive layer with a certain final thickness compared to a cohesive surface contact. The adhesive behavior of these elements is defined by the material properties. Cohesive elements are defined by the thickness, stiffness and strength of the adhesive. It is advisable to apply cohesive elements especially in places where crack development can be expected. It is assumed that at the beginning of loading there are no cracks in the adhesive layer, otherwise this phenomenon can be modeled by the absence of elements at the crack site. The relative displacements between the upper and lower surfaces, which are measured in the thickness direction and in the directions perpendicular, represent the opening of the crack face between the glued surfaces.

4. Use of FEM in the calculation of welding joints

Welding analysis is an important topic in engineering research and it is widely employed in the fabrication due to their advantage of improved structures performance, cost savings and easy implementation. However, welding application cause undesirable permanent distortion and residual stress in the material. Welding has about 26 imperfections e.g. cracks, porosity, worm hole, inclusions, lack of penetration, lack of fusion, lack of fit, undercut, excessive weld overfill, insufficient weld throat, root overfill, misalignment, weld sag, incomplete root, cold lap, arc strike, sputter etc. [8]. With all this imperfection simulation parameter will be in challenge. Material modelling is, together with the uncertain net heat input, one of the major problems in welding simulation.

FEM analysis was carried out in Solid Works software. The first step contained of modeling solid bodies of sheet metal plates. The dimensions of the metal plates are 25 mm width, 100 mm length and 0.8 mm thick. Despite the spatial volume, the modeled metal plate is defined in Solid Works as a sheet metal, which will make it in FEM evaluation a 2D object. Modeling of assembly (Fig. 4) was carried out, in a manner that two metal sheet bodies share the line of weld. Materials for the examined were set in FEM environment, but first they had to be defined in a library using properties specified by manufacturer.

Fig. 4 *Computer model of weld.*

A finite element model comprises a system of points, called “nodes”, which form the shape of the design. Connected to these nodes are the finite elements themselves which form the finite element mesh and contain the material and structural properties of the model, defining how it will react to certain conditions. The density of the finite element mesh may vary throughout the material, depending on the anticipated change in stress levels of a particular area. Regions that experience high changes in stress usually require a higher mesh density than those that experience little or no stress variation.

Next step was to perform the tests for the yield strength. Each assembly had its sheet metal plates materials chosen accordingly to the test. Then the weld method was chosen as edge weld, specifically one side groove weld. Reason for this weld is that Solid Works did not offer laser weld function. But principle of welding method is that it melts the materials in weld spot, which makes them unite after cooling. In this manner the groove weld was the only one which can be put on a weld line, making connection between welded metals, and is easy to work with i.e., changing properties. For simulating tearing process, one side of the assembly (one sheet metal plate) has to be fixed, by fixing any linear movement or rotational, while the other side (second sheet metal plate) have defined linear force. The linear force changes between computed force for weld for first and second sheet metal plate material. One of the last things before results is to define appropriate size of the mesh, so that no local maximum appears in the results.

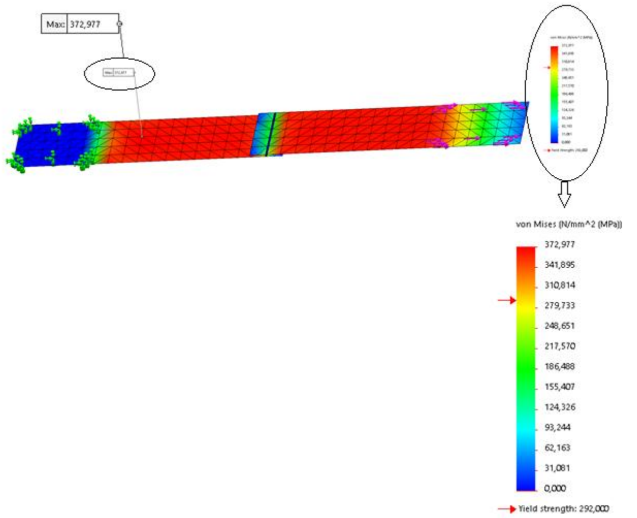

Fig. 5 *Example of FEM analysis for a pair of TI -TL materials.*

The ultimate stress is gained in a same manner as for the yield strength, but with the different changing forces. Biggest challenge is to determine force value for which, examined weld will break. The Solid Works does not dispose a function where the FEM will determine how much force breaks examined weld. Therefore some calculation through coefficients were adopted. First step is to run study with any force value. The bigger the better. This gives first coefficient, which is factory of safety coefficient. If this coefficient has determined value of safety to 1, then it will make a range of coefficients smaller than 1. Multiplicating of the force and the lowest coefficient gives a value of the force for the yield strength for the weakest material. Further multiplication of this force with coefficient for the weakest material of the ultimate strength to yield strength, rises this force to the values, when weld breaks.

Welds were examined for the following materials:

- HX340LAD+Z (Re=414MPa, Rm=473MPa, Zn layer 111 $g.m^{-2}$,
- TL1550-220+Z (Re=292MPa, Rm=373MPa), Zn layer 104 $g.m^{-2}$,
- HCT600X+Z (Re=346MPa, Rm=654MPa), Zn layer 105 $g.m^{-2}$,
- DC04 (Re=197MPa, Rm=327MPa), without Zn layer.

Rm is ultimate strength (stress) for material and Re is Yield strength. Table 1 shows some results of the FEM analysis. There are FEM weld analysis results for different material combinations in this table.

Table 1: *Results of the FEM weld analysis.*

Combination of materials (fixed – pulled sheet)	Loaded by Fm for pulled sheet [MPa]	Loaded by Fm for fixed sheet [MPa]	Force when weld breaks max F [N]
DC-DC	331.443	331.443	6452.6495
TL-TL	378.068	378.068	7359.5429
TL-DC	331.443	378.068	6492.8157
TL-HX	479.427	378.068	7360.4713
HX-DC	331.443	479.427	6492.8157
HX-HCT	662.886	479.427	9332.8498
HCT-DC	331.443	662.886	6492.8157

5. Conclusions

The production of cars with lower weight and thus with lower fuel consumption, follows the ecological requirements of reducing materials of various thicknesses and qualities, whether plated or unplated, but also the connecting of ferrous and non-ferrous metals. Their application in the automotive industry opens new opportunities for designers. These consist in the optimal use of the properties of different types of sheets, which can be combined into one unit and thus affect the strength, stiffness or resistance to corrosion and resistance to chemical aging in different parts of the mold.

Glued joints appear in the automotive industry in many types, both in terms of functional stress and in terms of design. It can be said that the bonding is either complementary and sealing (bonding and cementing of bodies for sealing, vibration damping, corrosion protection, application of reinforcements) or can, in specific cases, represent welding technology in structural strength joints.

Welding is the most commonly used process for permanent joining of machine parts and structures. Welding is an expedient by which metals may be joined by increasing the temperature of the work pieces to their fusion point and allowing the molten metal formed to flow together and solidify.

Due to the influence of the welding residual stress, residual plastic deformation, heat affected zone and stress concentration effect the fatigue life of welded components is far lower than the parent metal.

To calculate strength of welded structure and to find behaviour under cyclic load, it is very important to do analysis according to real life problems, so that analysis results can be used to predict the life of structures. After welding of structures there are many factor involve defining parameter in the finite element analysis.

Acknowledgement: This work is a part of these projects VEGA 1/0154/19 “Research of the combined technologies of joining dissimilar materials for automotive industry”

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