Application of glued joints in passenger cars

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Abstrakt Gluing is a technological process in which an inseparable connection of two or more parts from the same or different materials is created using another material - an adhesive. This joining technology is increasingly appearing in the automotive industry. The automotive industry is a decisive industry and a driving force for the development of the Slovak economy. Glued joints appear in the automotive industry in many types, both in terms of functional stress and in terms of design. Gluing of metals allows us to lighten structural systems. The great advantage of gluing technology is that it eliminates the formation of electrolytic corrosion between two different metals and dampens the vibration of the structure. Bonding is also cheaper than soldering and welding. There is advantages of using glued joints in the automotive industry and solution of the problem of strength calculation of these bonded joints in this paper.

Key words Automotive industry, gluing, strength calculation

1. INTRODUCTION

Gluing technology has been known for several millennia. For example, mud or resin was used as the adhesive. The first proven use of glue dates back to 4000 BC, when archaeologists who, when examining historic burial sites, found disturbed pottery that had been glued with resin from tree juices. In the period 1500 - 1000 BC, glue became mainly a method of assembly. In ancient Egypt, they used glue to artificially decorate wooden products. The Babylonians, in turn, connected the stone structures with bitumen, and the Romans glued their ships together with a mixture of tar and beeswax. In the Middle Ages, the production of adhesives of animal origin developed [1-3]. People used bones, leather, starch, cottage cheese or rubber as binders.

The first commercial glue factory was opened in the Netherlands in 1700 and used animal skin as the main raw material. The great turning point came with the industrial revolution, when new materials were used to make the glue and synthetic glue was created. The first polymer synthesized was nitrocellulose.

Around 1965, other aircraft manufacturers switched to gluing technology and began to apply it to a greater extent in other industries as well [4, 5]. Today, adhesives are part of almost every industry. Gluing technology can currently be found, for example, in construction, aviation or healthcare, and last but not least in the automotive industry, where adhesives are used not only to glue body parts, but also to seal and dampen vibrations [6]. At present, adhesives are produced exactly according to the customer's requirements and it would be difficult to find a field where it would not be used. The great advantage of gluing technology is that it eliminates the formation of electrolytic corrosion between two different metals and dampens the vibration of the structure. Gluing is also cheaper than soldering and welding [7 - 9].

Gluing also has disadvantages, which include a demanding modification of the contact surfaces, the susceptibility of joints to creep under long-term stress at higher temperatures [10]. Metals are gas-impermeable materials, characterized by good adhesion properties and high heat resistance which allows the application of adhesives at normal and elevated temperatures.

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 [11].

This paper gives an overview of the advantages of using glued joints in the automotive industry. It is devoted to the problem of strength calculation of these bonded joints.

2. CHARACTERISTICS OF GLUED JOINTS

The theory of gluing (adhesive bonding of parts) is based on the relationships of molecules and their interaction. According to the latest findings, it is necessary to assign relationships resulting from non-molecular structure. Adhesion is related to the molecular structure. Physical forces, chemical bonds and intermolecular forces will continue to be applied [12].

It is difficult to create mutual attraction between two solid materials without the use of glue, as these materials would have to approach each other at a molecular distance and would have to be completely straight, parallel and free of all impurities. Therefore, an adhesive in the form of a liquid substance is used to induce this mutual attraction between the solid materials. The result is a non-detachable joint, which uses adhesive forces between the adhesive and the material and the actual cohesion of the adhesive [13, 14].

Advantages of glued joints:

- increased stiffness of the parts to be joined,
- tightness of joints (no need for additional sealing),
- good damping properties (noise, vibration),
- increased safety in case of failure,
- weight loss,
- possibility of joining materials of different sizes and thicknesses,
- increase of corrosion resistance of the car body, both chemical and electrolytic (adhesive is an electrical insulator),
- possibility of joining various materials (steel-glass, rubber-steel etc.),
- no damage to the protective layer of galvanized sheets,
- flat mounting of car body plates ensures uniformly distributed tension in the glued joint (which increases overall strength and rigidity of the whole car body).

Disadvantages of glued joints:

- technological complexity of preparation of glued surfaces,
- long curing time of the adhesive, maximum strength of the glued joint reaches after some time,
- low temperature resistance,
- aging of the adhesive,
- low peel and splitting strength,
- non-demountability of glued joints.

The main advantage of joining parts by gluing is the use of this technology where it is not possible to create a joint in other ways eg different types of materials, complex shapes, etc. [15]. Bonding has many advantages and disadvantages, but this work focuses primarily on the advantages and disadvantages of using adhesive technology in the automotive industry and with regard to the design and stress of the bonded joint.

3. GLUED JOINTS IN PASSENGER CARS

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. Some applications of glued joints can be seen in Figure 1.

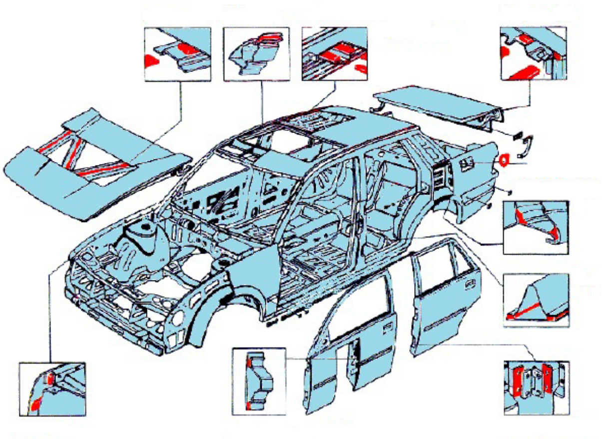

Fig. 1 Overview of glued joints of the car body [16]

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. Zinc adheres to the electrodes and there is a problem at the weld seams to maintain the protective function of the coating.

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 [17, 18], 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.

4. STRENGTH CALCULATION OF GLUED JOINTS

Glued joints can be loaded statically or dynamically and their material properties are determined primarily for three characteristic load cases: tension, shear and peel. As a rule, the pressure is not specified because the compressive strength of the glued joint is incomparably higher than for other types of stress and is difficult to achieve. These characteristic load cases usually occur in different combinations (eg tension - shear, peel - tension). In special cases, however, these load cases can be encountered separately (Firure 2) (eg net tension or clean shear).

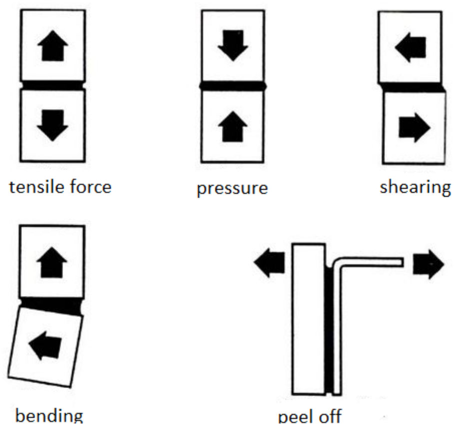

Fig. 2 Types of stresses of glued joints

The glued joints have a high shear resistance. Very badly tolerated tensile force. Therefore we shape them so that the joint is loaded only by shearing.

The glued joint is loaded with force *F* (Figure 3). In this case (assuming the flange material is inelastic), both parts are shifted by length *e*. If Hook's law applies to the adhesive, the voltage τ is the same over the entire length of the connection *l*.

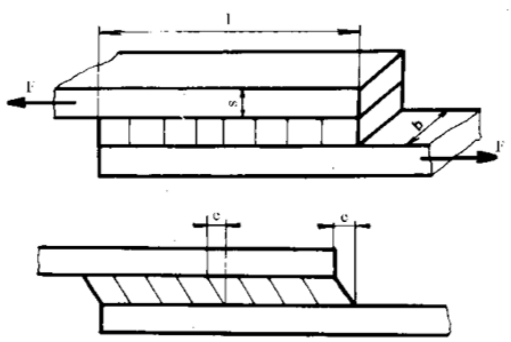

Fig. 3 Glued joint stressed on shear

The basic calculation equation is based on the mean stress τ equally distributed over the length of the joint and we compare it with the allowable stress τ_D.

$$\tau = \frac{F}{b \cdot l} \leq \tau_D \qquad (1)$$

$$\tau_D = \frac{\tau_p}{k} \qquad (2)$$

where k - safety factor, F – force, l - length of the connection, b - joint width, τ - tensile stress, τ_D - allowable tensile stress.

Experiments showed these values τ_p for steel are

$$\tau_p = (23 \div 54) \cdot 10^6 Pa \qquad (3)$$

Recently, at ever faster evolving computer technology and available literature, we can encounter modern numerical methods, such as finite element method (FEM) [19]. 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 [20]. 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) [21, 22]. 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. 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.

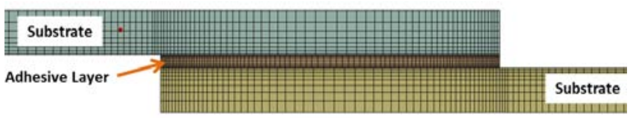

Fig. 4 2D plain strain finite element model of bonded joint

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.4). 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.

5. CONCLUSIONS

Glued joints appear in the automotive industry in many types, both in terms of functional stress and in terms of design. At present, car body plates are most often joined by resistance (spot, seam and projection) welding technology. These disadvantages include, for example, problematic joining of sheets of different thicknesses and qualities, or thermal influencing of the welded area. By using the bonding technology we avoid these problems and we can take advantage of the many advantages it offers in the automotive industry.

With the development of the automotive industry, the ever-increasing number of cars on the road and the related increase in road accidents, manufacturers are increasingly concerned with the passive safety of cars. When the new vehicle is put into operation, there is a so-called homologation where the car must meet all the requirements specified in the standard. One of the many conditions is that the car must guarantee a prescribed level of passive safety, which is tested under predetermined conditions. At present, we are still looking for possibilities and technologies that would mean cheaper, faster and more accurate production of cars, while maintaining the conditions and criteria required by us. These technologies undoubtedly include computer design of cars. Everything is done on computers from designing, designing individual components, to demanding strength calculations and simulating vehicle barrier tests. In all calculations and simulations, the aim is to bring the computational model to reality as much as possible. Numerical simulation of the glued joint allows to reduce the time for product development, production and production costs.

Before the actual gluing process, it is necessary to make a suitable design and choice of materials for gluing. In simple terms, the structure should be designed to adhere well. Nowadays, however, it does not work like this, the designer will design the structure and only then decide how this structure will be manufactured (what will be glued, what will be welded, etc.).

References

1. Sedliačik J., Procesy technológie lepenia. TU Zvolen, III. vydanie, (2003), 88p.
2. Kohl, D. et al., Influence of manufacturing methods and imperfections on the load capacity of glued-in rod. Journal of Adhesion. Volume: 96 Issue: 8, (2020), p. 738-759.
3. Walame, M. V., Ahuja, B. B., Profile modification of adhesively bonded cylindrical joint for maximum torque transmission capability, International Journal of Modern Engineering Research, 4/ 8, (2013), p. 1-11.
4. Babjak, Š. et al.: Lean creative automotive product design (LCAPD). A Jövő Járműve. Vol. 5, no. 3/4 (2012), p. 70-78.
5. Lašová, V. et al., Výzkum spojení kompozitních a kovových částí strojů - Dílčí zpráva V002, Plzeň, 2011.
6. Brezinová, J., Kender, Š., Utilization of innovative techniques in ultra-light automobile production. Trans and Motauto World. Vol. 3, no. 3 (2018), p. 102-105.
7. Lee, A. T. et al., Influence of curing conditions on mechanical behaviour of glued joints of carbon fibre-reinforced polymer composite/concrete. Construcion and building materials, Volume: 227 Article Number: UNSP 116385, (2019).
8. Dukarska, D., Lecka, J., Polyurethane foam scrap as MUPF and PF filler in the manufacture of exterior plywood, Annals of Warsaw University of Life Sciences - SGGW, Forestry and Wood Technology, Warszawa, No. 65, (2008), p. 14–19.
9. Baworski, A., Garbala, K., Czech, P., Witaszek,K. Estimation of the ability to use a mass of air from amoving vehicle in wind turbine propulsion. Scientific Journal of Silesian University of Technology. Series Transport. 88 (2015) 5-17.
10. Dúbravčík, M., Kender, Š., Accelerating of ultralight composite´s production processes. Interdisciplinarity in theory and practice. no. 9 (2016), p. 137-141.
11. Šmidriaková, M., Sedliačik, J., Príprava tvrdiva pre malamínformaldehydové lepidlo na zvýšenie vodovzdornosti lepeného spoja, Acta facuttatis xylologiae Zvolen, 52(2), (2010), p. 73-80.
12. Brezinová, J. et al., Materiály a technológie v automobilovej výrobe. 1. vyd., Košice: TU v Košiciach, (2019), 355 p.
13. Hisen, P., Elisová, L., Využití lepení ve stavbě automobilových karoserií. Tématický magazín, Svařování - dělení – spojování materiálů. TM vydavatelství. Praha, (2003), s.32.
14. Doubek, P., Kolnerová, M., Základy technologie lepení karosářských výlisků. Liberec: (2014), Technická univerzita v Liberci.
15. Babjak, Š. et al., Composites in the Automotive production, Annals of faculty engineering Hunedoara - International journal of engineering. Vol. 10, no. 3 (2012), p. 77-82.
16. Maláková, S. et al., Glued joints in the automotive industry. Acta Mechatronica, (2019), Roč. 4, č. 4 (2019), p.23-28.
17. Kender, Š. et al., Advantages of using composite materials in automotive manufacture process. Trans&Motauto World. - Sofia (Bulharsko) : Scientific Technical Union of Mechanical Engineering, Roč. 5, č. 1 (2020),p. 3-5.
18. Czech, P., Wojnar, G., Warczek, J.: Diagnozowanie uszkodzeń wtryskiwaczy w silnikach spalinowych pojazdów przy użyciu analizy bispektrum i radialnych sieci neuronowych, Logistyka No. 3, (2013), p. 1181-1187.
19. Dúbravčík, M., Babjak, Š., Kender, Š., Product Design Techniques in Automotive Production. American International Journal of Contemporary Research. Vol. 2, no. 5 (2012), p. 43-54.
20. Camanho, P. P., Davila, C. G.: Mixed-Mode Decohesion Finite Elements for the Simulation of Delamination in Composite Materials, (2002), NASA/TM-2002-211737.
21. Kováč, M. et al., Vybrané metódy testovania automobilov, 1. vyd., Košice: Technická univerzita , (2015), 121 p.
22. Hassanieh, A. et al., Glued-in-rod timber joints: analytical model and finite element simulation. Materials and Structures, 51/61, (2018), p. 1-16.