Providing dismountable rivet bonded joints through the use of hot-melt adhesives

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Abstract. The article presents the comparative analysis of adhesives used for obtaining rivet bonded joints. The dismantling characteristics of adhesive rivet bonded joints of different types are considered. It is shown that the application of hot-melt adhesives proved to be a far more advanced technique used for the materials being joined.

Today aluminum alloys and composites (carbon-filled plastics) are widely used in mechanical engineering. Joining parts from aluminum alloys or carbon-filled plastics to steel parts of the bearing frame is extremely difficult or impossible to perform with the use of traditional welding. For this reason the riveting technique has been increasingly used in mechanical engineering in recent years.

In the process of riveting, the protruding end of the shank is upset by hammer blows to form the closing head of a required shape and size [1]. This technology is more than 2000 years old. During excavations archeologists often discover various objects in which this joining technique was applied. At the beginning of the 19th century riveting was used as one of the main methods for producing permanent joints. The Eiffel Tower in Paris, for instance, is assembled directly with the application of rivets. However, the development of welding technology considerably reduced the sphere of applications of riveted joints. However, when manufacturing areas dealing with permanent joints started to use dissimilar materials, riveting moved to the foreground again.

In recent years riveted joints have also found use in the assembly of dissimilar materials or materials with poor weldability, heat-treated or finished precision components for which heating is prohibited, and as a result it is impossible to apply welding [2-3]. In certain cases riveting is the only method for producing joints.

The main disadvantages of riveted joints are high labour-intensive costs, high consumption of metal, weakness of the working cross-section and the effect of stress concentration caused by the holes required for rivets. The strength characteristics of riveted joints can be improved by adding glue (rivet bonding). The idea of rivet bonding is that the technique combines the two independent operations – «bonding» and «riveting». In mechanical engineering the process of making uncured rivet bonded joints has become the most widespread method. The core of this technological process is that rivets are fitted after the adhesive is applied, but before it is cured. [4].

Epoxy adhesives have been traditionally used to make joints [5]. The main application advantages of epoxy adhesives are good joint sealing, simplicity and low cost of this method, good corrosion resistance, no need for heating and lack of stress concentration in the joint area.

The drawbacks of epoxy materials include high requirements imposed on the quality of surface preparation, a long time of curing, toxicity and difficult dismounting. The high strength of glue and lack of thermoplasticity require additional power load and extra tools which definitely complicates dismantling. Furthermore, the faying surfaces of the bonded parts may be damaged while dismounting.

An alternative type of adhesives applied to create joints is hot-melt adhesives that are a form of thermoplastics [6-7]. Unlike epoxies that are thermosetting resins, hot-melt adhesives are reversible. Initially solid adhesives get melted and become viscous-flow at elevated temperatures. Once adhesives cool, they revert to the original solid state. This method provides a strong bond line. Depending on a brand, bonding temperatures range between 100 - 200ºC [7].

The basic requirements for hot-melt adhesives are a great bond strength and environmental resistance [8]. All that prevents the joint from altering its characteristics while in operation.

The advantages of hot-melt adhesives applied together with rivet bonded joints are that they are easily removed and provide increased strength and stiffness to structures under static, dynamic and vibration loads. This is because the structure distortion (e.g. in the three-point bending) is not accompanied by load-bearing points moving with respect to each other [9]. All these features increase the service life of rivet bonded joints.

Dismounting of rivet bonded joints with hot melt adhesives is ensured by the fact that thermoplastic hot-melt adhesives go to a liquid state and lose their

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tackiness when heated [10]. Table 1 shows the labour coefficient for assembly and dismounting of rivet joints, rivet bonded joints with epoxy adhesives and rivet bonded joints with hot-melt adhesives.

Table 1. The labour coefficient for assembly / dismounting of joints

Type of joint	The labour coefficient, %	
	Assembly	Dismounting
Rivet joint	100	100
rivet bonded joint with epoxy adhesive	160	180
rivet bonded joint with hot-melt adhesive	160	130

The sequence of operations on dismounting rivet bonded joints with hot-melt adhesive looks as follows: first, the bond line is cleaned, any dirt or paint, if there is any, is removed from the bond line. Then, rivets are drilled out (like during the process of rivet joint dismounting). After that the bond line is being heated with the hot air gun until the hot-melt adhesive gets melted (from 100 to 200°C). When heated the solid adhesive becomes viscous-flow and joint surfaces get separated without any application of load. The rest of molten adhesive is removed from the plate surface with cloth. The result is a clean and tidy surface suitable for repeated bonding or riveting.

When producing rivet bonded joints with epoxy adhesive it is also necessary to observe the microclimatic parameters of a working area. High humidity causes curing to decelerate or even stop [5] whereas hot-melt adhesives are moisture resistant [10].

Thus, we can draw a conclusion that using thermoplastic hot-melt adhesives is one of the most efficient ways to manufacture rivet bonded joints.

Hybrid joints combining adhesive bonding with rivet joints can generally be created in one of three ways:

- the sequential method (installing rivets after the adhesive layer has hardened);
- the «fixing» method (installing rivets before adhesives have cured);
- the injection method (joining parts with a rivet joint before injecting the adhesive into the gap between the components).

Each of these technologies has advantages and disadvantages (table 2). The choice of technology is based on the conditions of a particular production. If the parts are assembled for single-unit production, then the first and third technologies are the most effective. The application of the second technology is preferable for mass production. This is due to the fact that this technology does not require any changes in riveting modes and the equipment earlier used for riveting can be applied.

The «fixing» method (when joining the components together is followed by the hardening of the adhesive layer) is widely used for automotive body repairs.

This alternative technology provides a higher level of joint efficiency compared to adhesive bonding, riveting or the technology when rivets are installed after the adhesive has cured. The «fixing» method also enables to use technologically recent adhesives providing a strong adhesive layer.

The principle drawbacks of the method are the rivet tool contamination caused by excessive uncured adhesive and the increased drill wear [3].

Table 2. Comparison of different methods of creating rivet bonded joints

Methods of creating rivet bonded joints	Advantages	Drawbacks
The «fixing» method: riveting before adhesive curing	- high quality of the adhesive layer; - a wide range of adhesives	- contamination of drills by excessive uncured adhesive
The sequential method: riveting after adhesive curing	- uniform thickness of the adhesive layer; - no clamping is required; - a wide range of adhesives	- potential damage of the adhesive layer while rivet; - the increased wear of drills
The injection method: riveting before adhesive injecting	-high quality of the adhesive layer	- a special tool is required to apply the adhesive; - the increased assembling time required for adhesive hardening; - the limited range of adhesives

The quality of rivet bonded joints depends to a large extent on a rivet and adhesive type chosen. Being placed like weld points with a certain span the rivet holes represent further stress raisers. Therefore, each type of joint requires a particular type of rivet.

The hybrid joints used in the automobile industry and machine building are mainly based on two rivet types: blind and metal piercing rivets. Typically, metal piercing rivets are called «self-piercing» due to the fact that their installation does not require any pre-drilled holes. Self-piercing rivet bonded joint is shown in fig.1. However, they can be installed on a flat surface only (with no high spots), e.g. in door openings or window screens. While setting such rivets the protrusion is formed on one side

only. At the same time the rivet 'cap' is positioned close to the part surface that allows it to be almost imperceptible after painting. The main disadvantage of self-piercing rivets is that their installation requires special equipment whereas blind rivets are installed with traditional riveting hammers.

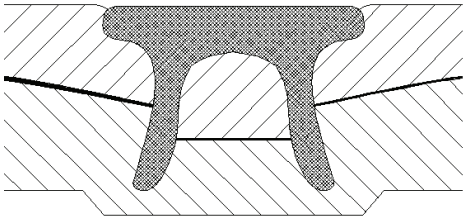

Fig.1. Self-piercing rivet bonded joint.

Blind rivets require pre-drilled holes. Therefore, the use of such rivets is undesirable for the assembly of large machine parts with numerous holes because there is a high risk of the holes` mismatch caused by the displacement of plates relative to each other. Blind rivet bonded joint is shown in fig.2.

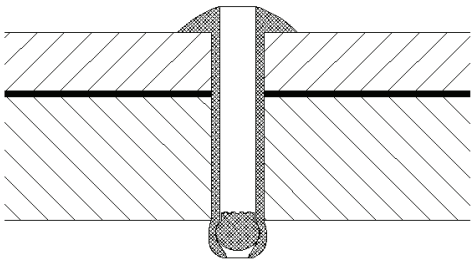

Fig.2. Blind rivet bonded joint.

Rivet joints comply with the condition according to which any mechanical loads are taken by rivets. However, rivet bonded joints do not satisfy it, for the adhesive applied shares load stresses with the rivet [5]. The long bond line results in the redistribution of stresses. Therefore, the span between rivets can be increased.

The type of adhesive depends on a particular method applied to create a rivet bonded joint. Riveting before adhesive curing allows film, phenol-formaldehyde and hot or cold cure epoxy adhesives to be used because in comparison to other methods of rivet bonding this one provides no restrictions on stress-strain behavior of adhesive (i.e. on its brittleness). When a rivet bonded joint is subjected to loadings the adhesive layer takes a large part of stresses thereby relieving rivets and reducing the strain of plates. For this reason, cold cure epoxy adhesives with encapsulants are a more perspective material used for automotive body repairs [8-9]. Fig.3 shows the behavior of epoxy adhesive with encapsulants under shear stress 50% of failure load.

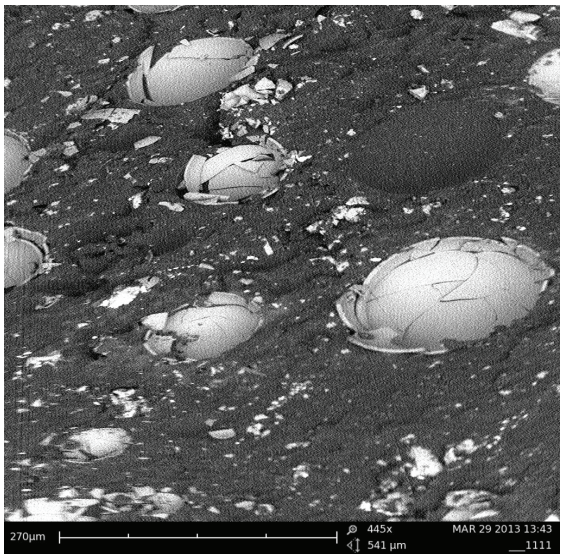

Fig.3. Epoxy adhesive with encapsulants under shear stress 50% of failure load.

The analysis of strength characteristics of different rivet bonded joints is given in accordance with industry standards GOST 1.00872-77 [10]. Some tests were performed to determine the maximum shear load of rivet bonded joints. The test samples of rivet and rivet bonded joints comply with the requirements of GOST 6996-66. The test results are presented in Table 3. Once the tests have been conducted, mean failure load is calculated.

Table 3. Test results of the calculations of maximum shear load

Test subject	Max. shear load, kgf (N)
Blind riveted joint	245 (2402)
blind rivet bonded joint	246 (2413)
Self-piercing riveted joint	251 (2462)
self-piercing rivet bonded joint	301 (2952)

The tests have shown that self-piercing rivet bonded joints provide the greatest shear strength whereas adding adhesives to blind riveted joints has not affected their strength. If rivet bonding of plates with different thickness is required, the strength of such joints is to be somewhat poorer compared to that provided by plates of uniform thickness. To reduce the negative effect of uneven gauge it is necessary to place the closing head on the side of a thicker plate. Thus, the use of modern rivets and adhesives allows the adhesive layer to take a greater part of stresses that, in turn, leads to the extended service life of joints and the reduced material deformation.

The fault cause analysis and possible preventive measures (remedies) are shown in Table 4.

Table 4. Typical faults in rivet bonded joints, causes and remedies

№ п/п	Fault	Cause	Remedy
1.	Deflection of joining plates	Excessive pressure on plates. Diameter of rivet shaft is larger than diameter of hole (the rivet is set forcefully)	Check the amount of force applied while setting the rivet. Check hole dimensions correspond to the diameter of the rivet shank
2.	Metal swell under the rivet heads	Riveting was performed without upsetting the rivet spots by straining tie	Upset the rivet spots by straining tie
3.	Hollows on joining plates and rivet heads	The wrong choice of tool, careless work	Use dedicated upsetting
4.	Incomplete closing head	The wrong choice of rivet type (the rivet shank is shorter than it is supposed to be)	Calculate the optimum length of the rivet shank and check presorting of rivets for those of required length has been performed
5.	Deformation (bend) of rivet shaft	The rivet shank of excessive length or misalignment of rivet axes and the bucking tool	Check the geometry of rivets corresponds to the calculations made
6.	Shank flattening	Clearance gap between joined parts	Check the geometry and proper bearing of parts
7.	Gapping between the closing head and the die head	The rivet head not tightly set	Check the rivet head is set tight. Remove any contamination as well as facings out of holes
8.	Mismatch between the closing head and the die head	Displacement of parts before or during the process of riveting. Angular position of drill while in operation	Provide visual inspection during the process of drilling. Make sure parts to be riveted are fixed and unmoved
9.	Misalignment of rivets	Non-uniform thickness of bond line, displacement of parts while adhesive bonding	Provide pre-spacing of rivet holes, make sure parts to be riveted are fixed and unmoved
10.	Starved spots	Initial poor fit of parts (increased clearance between joining parts). Air inclusions and voids in bond line.	Check the geometry and firm adherence of parts. Check the thickness and uniformity of adhesive layer. Comply with adhesive bonding technology
11.	Low adhesive strength	Contaminated surfaces of plates to be bonded. failure of cooling modes for adhesive	Check pretreatment procedures are correct. Observe the dedicated temperature modes and provide accurate time control while hot-melt heating or cooling

The quality control test takes an important part in the creation of rivet bonded joints. At an early stage it is monitored by visual inspection that there are no such faults as:

- undue local deformation of joining parts including their deflection while setting the rivet and metal swell under the rivet heads (this fault mostly occurs while riveting metal sheet 5 mm and thicker); hollows on joining plates and rivet heads.
- incomplete closing head;
- deformation (bend) and flattening of the rivet shank;
- gapping between the closing head and the die head;

-mismatch between the closing head and the die head along with misalignment of rivets;

- starved spots or peeling (low adhesive strength).

Thus, the tests conducted allow us to draw a conclusion that the adhesive used in a rivet bonded joint of high quality not only protects the inner surfaces of substrates from corrosion but also seals the joint off. It was found that rivet bonded joints provide a greater shear strength (by 15-35 %), even tear (by 20 %) and uneven tear (by 25-40 %) than corresponding rivet joints [1, 5, 9]. Furthermore, rivet bonded joints show better strength characteristics under dead-load stresses and vibration strain than similar rivet joints.

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