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ISSN 0543-5846
METABK 50(1) 67-70 (2011)
UDC – UDK 686.867:516.3:620.17:620.16:620.172=111

EFFECT OF ADHESIVE GEOMETRY ON THE TENSILE PROPERTIES OF AISI 1350 STEEL

Received – Prispjelo: 2009-09-18
Accepted – Prihvaćeno: 2009-11-24
Professional paper – Strukovni rad

It is utilized increasingly to use adhesive bonding in automotive industry to join structural components of metallic materials. The aim of this experimental study is to extend the information available to the automotive design engineer and contribute the better understanding of how the various geometrical shaped of steel parts affect the adhesive bonding. In this study, different types of lap joints, such as butt, step butt, scarf, tubular lap, were used to determine the mechanical strength of SAE/AISI 1350 steel. It has been observed that the cylindrical geometries can be subject to more stress compared to square specimens generally and the geometries with both tensile and shear stress can stand more stress per unit compared with the specimens with only tensile stress.

Key words: adhesives, joint geometry, tensile test, stress, elongation

Utjecaj grometrije lijepljenog spoja na vlačna svojstva čelika AISI 1350. U automobilskoj industriji sve je češća primjena spajanja metalnih dijelova lijepljenjem. Cilj ovoga eksperimentalog istraživanja je osigurati potrebne informacije inženjeru projektantu u automobilskoj industriji, o utjecaju geometrije uzorka i lijepljenog spoja na čvrstoću. U ovome istraživanju korištene su različite vrste preklopnih i sučeonih lijepljenih spojeva, za određivanje vlačne čvrstoće čelika SAE/AISI 1350. Zaključeno je da su uzorci kružnoga poprečnog presjeka mogli podnijeti veća naprezanja, u odnosu na uzroke kvadratnoga poprečnog presjeka. Uzorci u kojima su se pojavljivala vlačna i smična naprezanja, mogu podnijeti više naprezanja po jedinici površine u usporedbi sa samo vlačno napregnutim uzorcima

Ključne riječi: lijepljeni spojevi, geometrija spoja, vlačna čvrstoća, naprezanje, izduženje

INTRODUCTION

The use of structural adhesives in automotive industry is increasing steadily, as manufacturers become aware of the advantages that adhesives can offer, compared with the conventional techniques. However, not only the adhesive properties must be analyzed, the geometry must be taken into account as well [1]. It is theoretically and experimentally proved that, adhesive joints are more reliable than joints that are generated by conventional techniques such as screw bolt, rivet, welding, soldering, when designed according to working conditions. It is always possible to determine the strength values in the studies taking joint geometry, applied load type and direction into account [1].

Adhesive bonded joints can distribute load over a much wider area than mechanical joints. However, the design of safe and cost effective bonded joints is a major challenge. Engineers are required to have a good understanding of the influence of material and geometric parameters on the joint's strength [2]. Good design practice normally requires that adhesive joints be constructed in such a manner that the adhesive carries the load in shear rather than tension since bonds are typically much stronger when loaded in shear rather than in tension across the bond plate.

Lap-shear joints represent an important family of joints, both for test specimens to evaluate adhesive properties and for actual incorporation into practical designs. Generic types of lap joints that commonly arise are single lap, double lap, scarf, bevel, step, butt strap, double butt strap and tubular lap [3].

Joint behavior and joint strength depend on stress distribution over the joint. This stress distribution is influenced by joint geometry and the mechanical properties of the adhesive and adherents. The most significant parameters are: length of overlap, adherent thickness, adhesive thickness, adherent stress/strain behavior and adhesive strain/stress behavior [4]. The importance of adhesive joints was emphasized and it was argued the adhesives were alternatives to the other joint techniques. Especially, appropriate surface processing and adhesive selection was signified by Adams et al. [5].

Many studies have been done concerning the influence of adhesives on the mechanical strength of the joints both experimentally and numerically. The geome-

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try and loading conditions, nondestructive and destructive test methods that have to be considered in the lap, square and cylindrical adhesive and joints were reviewed by Adams et al. [5].

Derewonko et al. [2] investigated non-linear analyses of adhesively bonded joints under tensile lap shear loading. Non-linear analyses and laboratory tests were performed for two different adhesive thicknesses. The results of laboratory tests were complied with the results of finite element simulations.

Campilho et al. [6] studied a two dimensional numerical analysis to assess the influence of several geometric changes on the tensile residual strength of repaired carbon fibre reinforced polymer (CFRP) composite plates. The authors concluded that with the correct joint configuration, the residual strength can be increased by 27 % for single-lap joints and 12 % for double-lap joints. The joint strength of reverse-bent joints was found to be up to 40 % higher compared to flat joints using various substrate materials, adhesives and overlap lengths [1]. Goeij et al. [7] revealed an overview of studies performed on adhesive composite joints under cyclic loading on and to serve as a starting point for designers who need information on experimental and analytical methods of composite adhesive joints.

The problem is the lack of reliable data concerning the strength of the various geometrical shaped joints. The objective of this study is to increase the amount of data available to the automotive design engineer and contribute the better understanding of how the various geometrical shapes of steel parts affect the adhesive bonding.

EXPERIMENTAL DETAILS

The test specimen most commonly used by manufacturers is the single-lap joint because many joints have this geometrical configuration [8]. In this study, various geometrical shaped specimens, which were prepared on lathe and milling machine both square and cylindrical shape having the diameter of 20 mm, cross sectional area of 20 x 20 mm and 200 mm in length, respectively made of SAE/AISI 1350 steel. The chemical properties of the work piece material extracted using spectrometer are given in Table 1.

Investigating the influence of various geometric shaped steel parts on the mechanical strength of the joints due to the necessity of a good contact between adhesive and adherent is aimed to promote with suitable mechanical strength. For this goal, tensile strength tests, carried for both square and cylindrical geometries mentioned below, were done at the following conditions which is shown in Figure 1; double scarf joint with a 30 and 60 degree taper, scarf joint with a 30 and 60 degree taper, butt, double step butt, tubular lap, single step butt, from 1 to 8, respectively.

Table 1 **The chemical properties of the SAE/AISI 1350 Steel / wt %**

C	Si	Mn	P	S	Cr
0,364	0,201	1,17	0,0135	0,0232	0,0186

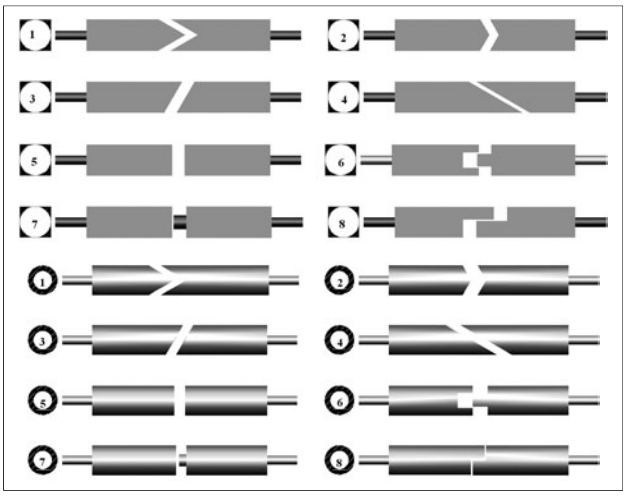

Figure 1 The schematic representation of specimens for both square and cylindrical geometries

Three different samples were tested for the each condition, whose average was taken. The thickness of the adhesive was chosen as constant (1mm).

Sikaflex® -255 FC, which has a high performance, elastic, gap-filling, one-part polyurethane adhesive that cures on exposure to form a durable elastomer, was used during the experiments. Sikaflex®-255 FC is manufactured in accordance with the ISO 9001/14001 quality assurance system. The properties of adhesive and reaction product are shown in Table 2.

Table 2 **Technical product data** [9]

Chemical base	One-part polyurethane
Supplier	Sika
Tensile strength (DIN 53504)	6 N/mm^2 approx.
Elongation at break (DIN 53504)	400 % approx.
Tear strength (DIN 53515)	12 N/mm^2 approx.
Tensile-shear strength (EN 1465)	4 N/mm^2 approx. (for a 4 mm applied thickness)
Service temperature (continuous)	-40 ^{0}C to +90 ^{0}C

The surface condition of adherents plays an important factor in establishing a strong and durable bond [8]. Before the application of adhesives, surface of specimens must be clean, dry and free from all traces of grease, oil and dust. The bond faces must be treated with a cleaning and activating agent or primed with the appropriate primer.

The procedure to prepare the samples is as follows: at the first stage, surface cleaning was performed by cellulosed solvent using a brush, then sika® activator and sika® primer 206G+p were applied. A pressure was applied by using clips to squeeze out extra resin in order to

Figure 2 Tensile testing machine

obtain the standardized thickness and correct adhesion between the joint components.

The surface roughness is also an important factor to produce a good mechanical strength. In this study, a TR100 Portable Surface Roughness Tester, which has *Ra* and *Rz* roughness parameters, *Ra*: 0,05-10,0 μm / *Rz*: 0,1-50 μm, RC analog filter, 6 mm tracing length, 0,25 mm /0,8 mm /2,5 mm cut-off length, was used to measure the surface roughness. The average roughness of the specimens was obtained as 2,42 μm.

The mechanical strength of the joints was evaluated by tensile testing machine, shown in Figure 2. AG-20kN tensile testing machine was used in tensile measurements at a cross head speed of 10 mm/min.

Table 3 **Values of stress and elongation according to the specimen**

Spec.	Stress Type T: Tensile S: Shear	Adhesion Area /mm^2		Stress /MPa	Elong. /mm
		Tensile /mm^2	Shear /mm^2		
S1	T	824,18	-	5,143	3,454
S2	T	480,62	-	4,193	1,878
S3	T	461,80	-	4,427	1,842
S4	T	800	-	6,590	4,606
S5	T	416,16	-	4,853	1,878
S6	T+S	400	684	15,457	3,393
S7	T+S	412,09	226,194	15,188	3,515
S8	T+S	400	380	10,678	4,787
C1	T	628,31	-	3,540	2,666
C2	T	362,85	-	5,217	1,878
C3	T	362,69	-	5,748	1,750
C4	T	628,31	-	6,447	3,454
C5	T	314,15	-	6,599	2,666
C6	T+S	314,15	366,60	8,230	1,818
C7	T+S	314,15	251,32	10,414	1,875
C8	T+S	314,15	140,22	15,370	1,818

The tests were conducted under ambient laboratory conditions, 22 ± 1 °C and 50 ± 5 % relative humidity. Before the tensile test, the specimens were stored in a support under ambient laboratory conditions 22 ± 1 °C and 50 ± 5 % during ten days. The stress and elongation values obtained from the experiment are given in Table 3.

The cylindrical and square were denoted as C and S, respectively. The stress is evaluated by the formula; $\sigma = F/A$, where F is the tensile load and A is the joint overlap area.

RESULTS AND DISCUSSION

The comparison of the stress values between cylindrical and square geometry is shown in Figure 3. Increasing stress trend is seen for cylindrical geometry from S1 to S8. An irregular behavior is observed for square geometry while a sudden increment is seen from S5 to S7 (218 %) and a rapid decrease from S7 to S8 (29,69 %) is shown. It is observed that the minimum stress difference is 2,17 % for square and cylindrical geometries (S4 and C4) at 6,59 and 6,447 MPa, respectively.

It can be seen from the Figure 3 that, σ_{min}= 4,193 MPa for square geometry, σ_{min}= 3,540 MPa for cylindrical geometry, σ_{max}= 15,457 MPa for square geometry and σ_{max}= 15,370 MPa for cylindrical geometry.

It is determined that the stress values of C2, C3, C4, C5 and C8 geometries are higher than corresponding S values compared to other geometries. The stress difference of square and cylindrical geometries is maximally 46,75 % as observed between S6 and C6. The stress values of square and cylindrical geometries are close for 1st to 5th geometries compared to other geometries.

The geometries of square specimens are ordered according to their stress values from highest to lowest as,

$$\sigma_{S6} >_s \sigma_{S7} > \sigma_{S8} > \sigma_{S4} > \sigma_{S1} > \sigma_{S5} > \sigma_{S3} > \sigma_{S2} \quad (1)$$

The similar order of the stress of cylindrical geometries is;

$$\sigma_{C8} > \sigma_{C7} > \sigma_{C6} > \sigma_{C5} > \sigma_{C4} > \sigma_{C3} > \sigma_{C2} > \sigma_{C1} \quad (2)$$

From Figure 4, it is observed that there is a decrease from S1 to S3 however; a rapid increment from S3 to S4

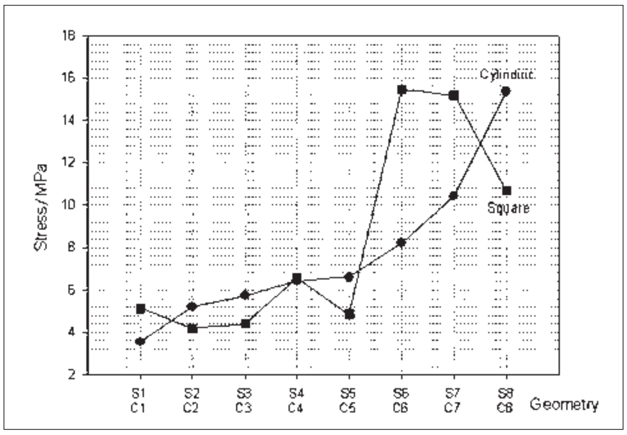

Figure 3 Comparison of stress values belong to cylindrical and square geometries

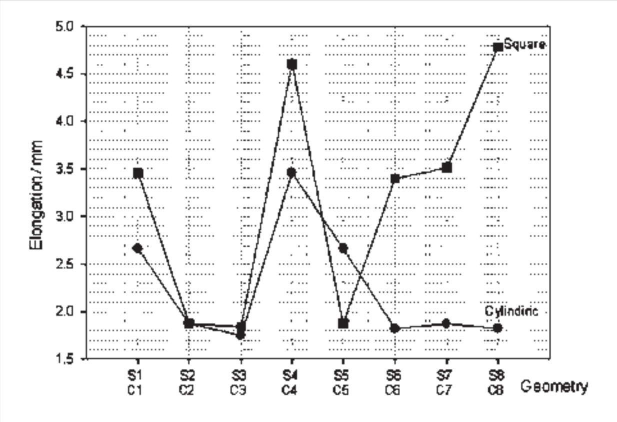

Figure 4 Comparison of elongation values belong to cylindrical and square geometries

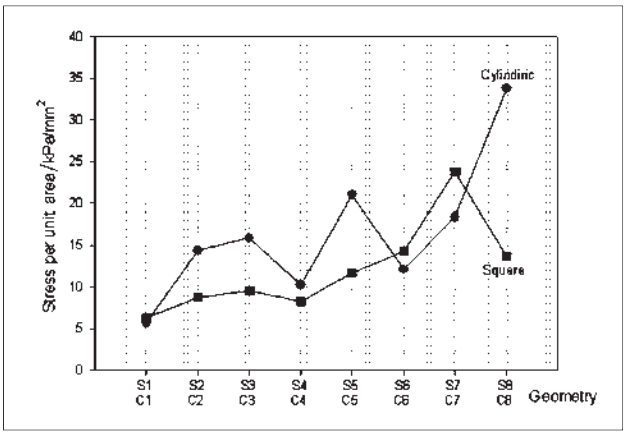

Figure 5 Comparison of stress per unit area values belong to cylindrical and square geometries

and then a rapid decrease from S4 to S5 are seen. Then, there is an increment from S5 to S8. Furthermore, a rapid decrease from C1 to C3 and increment to C4 (97,37 %), a decrease from C4 to C6 and unchanged trend from C6 to C8 is observed. S2 and C2 geometries have the same elongation value (1,873 mm). The maximum elongation difference is 62 % at 8th point for both square and cylindrical geometries. The maximum elongation amount is at the 4th geometry in cylindrical geometries, while the maximum elongation value is in 8th geometry in square types.

Furthermore, the variations of the stress per unit area with area of adhesion are given in Figure 5 for both square and cylindrical geometries. It is seen that the square geometry can be under stress per unit area up to 23,795 kPa/mm^2 (S7), while the cylindrical geometry can stand up to 33,826 kPa/mm^2 (C8). For square geometries, the geometries can be ordered according to stress per unit area as follows:

$$\sigma_{pua.S7}>\sigma_{pua.S6}>\sigma_{puaS8}>\sigma_{pua.S5}>\sigma_{pua.S3}>\sigma_{pua.S2}>\sigma_{pua.S4}>\sigma_{pua.S1} \quad (3)$$

Similarly, the stresses per unit area for cylindrical geometries are,

$$\sigma_{pua.C8}>\sigma_{pua.C5}>\sigma_{pua.C7}>\sigma_{pua.C3}>\sigma_{pua.C2}>\sigma_{pua.C6}>\sigma_{pua.C4}>\sigma_{pua.C1} \quad (4)$$

In equation (3) and (4), σ_{pua} is stress per unit area.

When the variations are considered generally, it is seen that the cylindrical geometry can stand to more stress per unit area than that of square geometry. If stress per unit area is considered, it is seen that the specimens with both tensile and shear stress can be used under more stresses compared to the geometries with only tensile stresses. The similar results were also reported by Adams et al. [3].

CONCLUSIONS

In this study, stress and elongation results are obtained using Sikaflex® -255 FC adhesive for various geometries. The following results are obtained:

1. Generally, cylindrical geometries provide more stress compared to square specimens.
2. Single step butt geometry (C8) showed the highest tensile strength for cylindrical geometry. Similarly, double step butt is the specimen with highest tensile strength for square geometry (S6).
3. Double scarf joint with a 30 degree taper showed the lowest tensile strength (C1) of both square and cylindrical types.
4. The maximum elongation difference is obtained at single step butt for both square and cylindrical geometries. The maximum elongation amount is at the scarf joint with a 60 degree taper in cylindrical geometries, while the maximum elongation value is in single step butt in square types.

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Note: The professional translator is Serhan Yamacli. Faculty of Technical Education, Mersin University Kartaltepe, Tarsus, Turkey.