Shear Strength Behaviour of adhesive bonded Polymer and Steel Surfaces

Z. Szakál¹, L. Zsidai², H. Al-Maliki³, M. Odobina⁴, A. Kári-Horváth¹

Abstract: During our work, we examined the features of the bonding of the polyolefines (UHMWPE, HD1000, HD5000), and fluorine polymers (PTFE), which are qualified as sticking hardly or not at all. In the course of the research we apply acrylic base and cyanoacrylate adhesives. For qualifying the glued bonding we used specimens with overlapped bonding made according to standard DIN EN 1465 and by breaking then we used tensile-test machine according to standard ISO 527-1. We make a proposal based on the results, onto the bandage forming come close to the strength of the base material relating to the examined polymers.

Keywords: adhesion bonding, shear strength, PP, UHMWPE, PTFE

1 INTRODUCTION

The development and adoption as well as testing of sticking technologies of machine parts [10, 21] made of engineering plastics comes into the foreground rather continually [3, 4, 5]. One of the main motivators of this is the vehicle industry, where the forming quick high strength and elastic component contacts have got crucial importance. Here during production (sticking body and casing elements) and repairing (broken plastics, the bonding of windscreens) structural adhesives are used equally [2, 7]. Due to this currently not only the development of polymer composites is going on, but the market of the bonding materials was transformed in the past 5-10 years totally. New and newer adhesives appear with additional surface treatment materials, which help the adhesion of cements and the increase of their strength.

The advantages of adhesion bonding:

- the constructional margin is growing,
- homogenous stress distribution,
- does not harm the structural materials,
- different structural materials can be bonded,
- may reduce the number of the machine elements,
- more aesthetic appearance.

We planned an overall experiment series, with the use of the most used engineering polymers and the new adhesion materials, with adhesives applied widespread in the industry in our present research. The adhesive substances are recommendation by Henkel Magyarország Ltd., we chose it from a product line of Loctite. The choice of the superglue and commonly-used one expand on structural adhesives, these are acrylic bases, and in the case of the superglues cyanoacrylate types [14].

We had it in our sight at the examination of engineering polymers qualified previously not at all bonding or as bonding hardly like polyolefin [8, 12], and the fluorine polymers [13, 18]. Present article reports on the results of gluing experiments made with plain polymer on a surface without the special surface treatment. We carried out according to the ISO 527-1 standard the shear test of lap joint made by the DIN EN 1465 standard with tensile-test machine. In the literature all the polyolefin [1, 9, 15, 22], all the fluorine [11, 19, 20] polymer basis articles, which added a footing to our examinations, are attached to the adhesive and mechanics features of plastics [6, 16, 17]. We call those non-metallic substances an adhesive, that the firm surfaces with the surface adhesion (adhesion), and their own solidity joint (cohesion). The sticking is an operation when a mediatory substance, the mucilage connects the surfaces of the solids with its help, and the peculiarities of the surfaces to be connected do not change. The material to be bonded must fulfil two conditions:

- The mucilage must to moisten the polymer. The surfaces energy of plastic has to be higher or equal with the surfaces tension of the mucilage.
- The polymer surface must have adhesion friend characteristics. This means that a chemical and physical interaction has to come into existence between the mucilage and the surface boundary layer.

In this case, the stock is unsuitable for gluing if these conditions do not come true, or the surfaces demand preparative treatment.

2 EXPERIMENTAL METHODS

The Table 1 shows the tested materials and to them owing (the Loctite made a choice based on Technical Data Sheet (TDS) recommendation) adhesive systems [14]. We examined selected materials on the experiment series sticking with themselves and with general construction steel.

2.1 The strength tests of the bonded connections

We examine the specimens prepared for the experiment plan adequately on a tensile-test machine, according to DIN EN 1465 standard. Although the standard mentions more solutions onto the forming of the specimens, we elected the simple overlap joining. Its disadvantage is tensile-tests that not clear shearing stress affects the gluing, identical forming is at disposal of all of the specimens at the same time. The knowledge of the absolute result is not necessary in the interest of the comparison because of this. We executed 5 repetitions in the course of our measurements. The tensile was managed by a Zwick Roell Z100 tensile test machine (Fig. 1). The maximum tensile load is 100kN of the tensile-test machine.
Table 1. Gluing experiment plan

<table>
<thead>
<tr>
<th>Material mates</th>
<th>Adhesive</th>
<th>Primer Activator</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP - PP</td>
<td>Superglue: Loctite 406</td>
<td>Primer: Loctite 770</td>
</tr>
<tr>
<td></td>
<td>Structural adhesive: Loctite 3035</td>
<td></td>
</tr>
<tr>
<td>PP – S235 steel</td>
<td>Superglue: Loctite 406</td>
<td>Loctite 770 just for PP</td>
</tr>
<tr>
<td></td>
<td>Structural adhesive: Loctite 3035</td>
<td></td>
</tr>
<tr>
<td>HD1000 – HD 1000</td>
<td>Superglue: Loctite 406</td>
<td>Primer: Loctite 770</td>
</tr>
<tr>
<td></td>
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<tr>
<td>HD 1000–S235 steel</td>
<td>Superglue: Loctite 406</td>
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<td>Loctite 770 just for HD 500</td>
</tr>
<tr>
<td></td>
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<td>HD 500 - S235</td>
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</tr>
<tr>
<td></td>
<td>Structural adhesive: Loctite 3035</td>
<td></td>
</tr>
<tr>
<td>PTFE - PTFE</td>
<td>Superglue: Loctite 406</td>
<td>Loctite 770 just for PTFE</td>
</tr>
<tr>
<td></td>
<td>Structural adhesive: Loctite 3035</td>
<td></td>
</tr>
<tr>
<td>PTFE – S235 steel</td>
<td>Superglue: Loctite 406</td>
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<tr>
<td></td>
<td>Structural adhesive: Loctite 3035</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1. Zwick Roell Z100 tensile-test machine

2.2 The specimen

The specimens used for the gluing were made by sawing from a 2mm thick plate in an identical size. The dimensions of the specimens are shown figure 2.

Fig. 2. Dimensions of the specimen [mm]

We fit the specimens with 12,5mm long overlap to each other, for the forming of the bandage. We chose the lap based on standard DIN EN 1465.

The requirements made on the gluing of the specimens:

- simultaneously the gluing of 5 specimens,
- overlap size are 12,5 ±0,1 mm,
- having identical compressive force,
- the specimens should not stick to the apparatus.

We bonded the specimens (what useful for tensile stress test) in the apparatus which can be seen on the Figure 3. We bonded two pieces of specimens it can be seen on the figure it together. We degreased the specimens with Loctite 7200 detergents before the bonding. We used Loctite 406 and Loctite 3035 adhesives gluing the specimens. We applied an additional surface primer implement (Loctite 770) activating the surface of the polymer. We treated the plastic surfaces with the primer implement first, and then we placed the necessary adhesive on the specimens and after put again the surfaces on each other.

Fig. 3. The apparatus used for the gluing

We made the bonding according to Loctite Technical Data Sheet (TDS) regulations. The TDS grants the preparation method of gluing surface, the time of adhesive of application and his solidification time.

2.3 The tested materials

Adhesives
The Loctite adhesives what were used are reactionary adhesives. Their application happens in a fluent state, and they are consolidated by a reaction between the surfaces. Loctite gave the adhesives for our experiment series. Table 2 contains the technical data of the selected adhesives.

**Loctite 406:** This superglue is designed for bonding of plastics and elastomeric materials where very fast fixtureing is required. His benefit is that is resists up to 120° temperature and has got low viscosity The Loctite 770 polyolefin primer increases the gluing solidity in case of the polymers which can be stuck difficultly. His fixing time is 2-10mp. It is colourless, transparent material.

**Loctite 3035:** This adhesive has got two components, it is a product with 1:1 mixing ratio, that mixes during carrying up to the surface thanks its tubulated from. It is recommended for substances with low surface energy, without a surface procedure. At most 15 minutes are its working times. It is equally suitable for gluing steel and plastic.

<table>
<thead>
<tr>
<th>Chemical Type</th>
<th>Components</th>
<th>Cure</th>
<th>Working Time, 25 °C, (before assembly)</th>
<th>Fixture Time</th>
<th>Full Strength</th>
<th>Shear Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>One part</td>
<td>Two component</td>
<td>Humidity</td>
<td>Room temp.</td>
<td>3min</td>
<td>10 h</td>
<td>72 h</td>
</tr>
<tr>
<td>Two part</td>
<td>Requires mixing</td>
<td>Humidity</td>
<td>Room temp.</td>
<td>7 min</td>
<td>10 h</td>
<td>72 h</td>
</tr>
</tbody>
</table>

**Construction steel (S 235 JR N)**

The one with a general function, not alloyed one of the most widespread kinds of steels, with a low carbon content (0.17%) and tensile strength is at Rm= 400-500 N/mm² disposal generally. It is easily workable, because of this its use is wide-ranging. For sticking standpoint it can be put among the easily bonding materials, so for any steels in the commerce it can be used with prescribed adhesive.

**Polypropylene (PP)**

The polypropylene is one of the best-known material and a most widespread substance of which use was made round. Cheap, we may call it a mass product nearly because of this. It has a limited tribology and mechanical properties, but in connection with his low price, it is widely used in the technical practice. The tensile strength at yield of the polypropylene is 30MPa. The polypropylene can be put among materials which sticking is difficult. Lasting, strong bonded joint can be made hardly because of very low surface energy. The technical literature suggest to from other bonding at this material.

**UHMW-PE (Ultra High Molecular Weight Polyethylene)**

They manufacture the polythene from the ethylene with polymerisation. The polypropylene is produced from ethylene with polymerisation. Two different types are used in the experiment series, the HD500, and HD1000. The tensile strength at yield of the UHMW PE is 20-24 MPa.

The gluing of the polythene it is important, that without a surface treatment only with special adhesives can be glued together. The adhesives are fit for this purpose if their chemistry and physical construction is consistent with that of the polyethylene well only. Those types are used usually as adhesives witch remain elastic in hardened condition.

**Polytetrafluorethylene (PTFE)**

Its construction is partly crystalline and has got thermoplastic substance partly. Its tensile strength 16-25 MPa and the elongation is 270-400 %. Because of the construction of the Teflon molecule it cannot be stuck, since the incomparably bigger one-fluorine atoms surround totally the coal atoms, a cohesive contact cannot be created with adhesive substance. The chemical stability is good for the Teflon one, and sticking its anti-adhesion surface demands a special procedure.

**3 DISCUSSIONS**

We make known the test results carried out during research with different construction adhesive of those plastics which can be glued hardly and are widely used in practice. During our work we stuck PP, HD500, HD1000 and PTFE plastics with themselves and with construction S235 JR N steels. We summarized in the table 3. the typical polymer tensile load values.

<table>
<thead>
<tr>
<th>Polymer type</th>
<th>Force [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP</td>
<td>1723</td>
</tr>
<tr>
<td>HD1000</td>
<td>1098</td>
</tr>
<tr>
<td>HD500</td>
<td>1269</td>
</tr>
<tr>
<td>PTFE</td>
<td>482</td>
</tr>
</tbody>
</table>

We made the tensile test according to a standard ISO 527-1. It is verifiable, that PP behaved rigidly, the rest of the plastic behaved toughly. The force value exceeded considerable stretching can be experienced on the tensile-test diagram. The specimens do not tear yet due to the metamorphosis, but their shape is lost already, this influences the solidity of the stuck bandages significantly.

In case of polypropylene specimens the gluing can be made difficultly, adhesion bandage does not take shape since the surface energy is small. We treated the surfaces with a primer modifying the surface energy in
the course of our gluing experiments. On the Figure 4 is visible, that with Loctite 406 adhesive the strength of the PP-PP lapped glued bonding can be only 60% of the strength of the base material. But in case of the PP-S235 JR N mates increases higher, so 85% can be reached of the base material strength. This good result in case of a material what is put among the hardly sticking materials. The good bandage strength is due to the primer treatment, which is the result of the adhesion connection between the polymer and cement, but if there is a substance contact when the polymer deformation capacity is obstructed to the perpendicular pulls.

The strength of the bandage increases higher then. The strength of the lapped, bonded, glued joint made with Loctite 3035 in case of polypropylenes appropriate, it is around 70% of the base material strength. The bigger strength of the structural steel does not influence the strength of the bandage here.

![Fig. 4. The results of the PP and S235 JR N mates with different adhesives](image)

In the case of the polyethylene the deformation of the stuck bandage is smaller, which causes the bigger stiffness of the steel, like we can reach the 85% of the tensile strength of reference polymer.

![Fig. 5. The results of the HD1000 and S235 JR N mates with different adhesives](image)

Because of the higher strength of the polymer, the softer Loctite 3035 structural adhesive proves to be weak, like this compared to the original substance 60% bandage strength can be reached. There is not a considerable difference in case of the structural adhesive on the own substance and the steel between the strength of stuck bandage created on matching.

![Fig. 6. The results of the HD500 and S235 JR N mates with different adhesives](image)

Because of the construction of the polytetrafluorethylene molecule it cannot be stuck, namely the greater scale fluor-atoms encircles the carbon
atoms, so they cannot produce cohesion connection with the adhesive. For the Teflon has got good chemical resistance, and anti-adhesion surface. Despite treating the surface with Loctite 770 primer then the strength of the lapped bonding made by Loctite 406 adhesive can reach 75% of the base metal strength. From PTFE surface the adhesive is divorcing partially down in this case, this substantial cross-section decrease can be attributed to this.

In that case when PTFE and S235 JR N type substances are, stuck with lapped bandage then the strength of the constructional steel makes impossible the change of the bandage cross-section, so the bonding strength approaches the polymer strength (figure 7). Producing the bonding of PTFE (that cannot be glued characteristically) with Loctite 3055 adhesive the strength of base material can be reached nearly. This structural adhesive adheres to the surface of the polytetrafluorethylene well, produces a stable construction creating a strong adhesion contact there. This constructional adhesive cannot follow the ensuing important cross-section reduction to the effect of tensile load of PTFE so the pulling off happens and it comes off from the surface. In case of PTFE and structural steel the steel does not allow the substantial metamorphosis of the bandage in the contact, like this the peeling off effect does not prevail, and does not detach the adhesive from the surface, strong stuck bandage coming close to the strength of the base material.

In case of mating polymer and steel beyond choosing the adhesive, the glue must be able developing good adhesion connection with both surfaces, that adhesive should be preferred which is more optimal for the steel.

Such case can take place, in the technical practice when it has to be produce glued bonding of polymer-polymer elements, beside the highest strength within reach of the given material. Then it should be consider that between the connection, made by lap it is expedient to put an intermediate rigid steel plate with this method the deformation ability of the bonding can be reduced. The smaller deformation results lower load on the glued bonding, the built in rigid part means a negligible effect so the whole structure.

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