Preliminary research of strength of glued connections of plastic elements

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Abstract. This paper presents the preliminary research of peel test of the adhesive bonding for materials using on parts of seating for public transport vehicles. Researches are focused on cooperation with the industry and their validity is conditioned by the need to automate the process of adhesive coat application. For the purpose of the experiment, two of the three materials composing the seat were selected: polyamide PA6 and polyurethane foam. Tensile strength tests were performed on polyurethane foam treated as the weakest component. At the further stage of the work, two adhesives were selected to for bond strength test. The first one was the adhesive used in the production of seats, the second one was selected on the basis of literature review. In both cases, adhesive was applied by spraying. Thus the bond strength was tested with the peel test as per EN 28510. The type of failure was also determined and the results are compared. Based on the obtained results, specific conclusions have been drawn to guide further research.

1. Introduction
Bonding of materials with adhesives is a widely used technique which owes its popularity to its ability to join completely different materials. However, due to the great variety of bonded materials and such variety of available adhesives, each particular process must be analysed on individual basis. Interest in the subject of bonding testing is also occurs in the literature [1]. Materials such as Teflon (PTFE) and polyethylene (PE) are hard to bond without a prior special treatment of the mating surfaces [2]. Material properties during adhesive bonding are important, e.g. porosity or roughness [3]. Also adhesives have different specifications. Hot-melt, solvent or water soluble kinds are distinguished, differing in terms of the utilised bonding mechanism, curing time required for attaining full strength and range of compatible materials. This vast variety of materials often necessitates determination of suitability of a particular adhesive for the materials in question and this need is also indicated by the adhesive manufacturers in the technical data sheets accompanying the product.

Production of seating systems for public transport is an example of production processes involving adhesive bonding of components. This process can be performed manually, for example with spray guns, or automatically with specially designed machines. Spraying can be utilised in both cases, the difference lying in repeatability that is characteristic of the automated process and enables determination of the most effective process parameters.

The objective of the tests carried out as part of this study is to look for the most effective parameters of the automatic adhesive application process and this, in turn, is the subject of the doctoral dissertation. This preliminary research is conducted to determine how the chosen materials behave in the actual
conditions in which they are used. This will enable identification of problems to be taken into account when planning future research projects. Besides verification of the materials to be bonded also the suitability of adhesive will be checked as part of this study.

2. Study method

Testing of adhesive bonded joints was conducted on seat padding materials bonded in the process intended to be automated. The materials that are most popularly used for fabrication of padding of public transport seats include: polyurethane foams (PUR), flame retardant upholstery fabrics and plastics such as PA6 and PPC. These materials are bonded together with substances commonly referred to as upholstery adhesives. The above materials classify as non-classical engineering materials in the same group as magnetorheological materials described in [4, 5]. The strength of these materials, similarly to adhesives and other plastics, depends additionally on the force application rate.

Selection of adhesive is based on the results of tests which cover verification of the bond quality by determining the ultimate load and mode of failure. The adhesive bonded joint has low peel strength, which is why such tests are often carried out and it is important to reduce this type of stress in such type connections [6]. Quoting one of seating manufacturers, the weakest element of the bond should be the foam and hence cohesive failure should occur in the bulk of the foam.

Taking this into consideration, two from the above-mentioned padding materials were chosen for testing: PUR and PA6. The specimens were made from the seat pad foam supplied by a seating manufacturer Kiel and from commercially available polyamide PA6 without any surface treatment. Bonaterm AS BT was one of the adhesives used in the tests which is the material indicated by above-mentioned seating manufacturer. The other adhesive was Pattex Universal Classic which, as declared by the manufacturer, is suitable for bonding plastics and soft foam materials.

Due to a variety of polyurethane products, including foams of different densities and solid materials used in applications including toothed belts or round belts, as described in the literature [7–10] it was indispensable to carry out strength tests of polyurethane as part of this study.

2.1. Specimens for the tensile strength tests

Standard shape specimens were used for the tensile strength tests in accordance with [11] (figure 1), both in the case of foam and polyamide. They were made using an appropriately designed die.

![Test specimens produced from a) polyurethane foam, b) PA6 polyamide.](image)

The test specimens were cut from the blanks using MTS Insight 50 kN strength tester: 5 No. from foam and 5 No. from polyamide. The specimens were all 150 mm long by 10 mm wide over the test section and the thickness was different depending on the material: 10 mm in the case of PUR foam and 2 mm in the case of polyamide.

2.2. Specimens for the peel test

In the first step of the peel test procedure the specimens were produced by bonding the tested materials in accordance with the recommendations of EN 28510-2 [12]. The specimens were made from
appropriately cut strips of the tested materials which are presented in figure 2. The section to receive adhesive was marked on the specimens. The specimens were all 25 mm wide and 400 mm long by 10 mm thick in the case of PUR foam and 200 mm long by 2 mm thick in the case of polyamide with 150 mm long section for adhesive application in both cases.

**Figure 2.** Strips of: a) polyurethane foam, b) PA6 polyamide.

In addition, the surface roughness of polyamide was checked with HOMMEL TESTER T1000 and the results obtained with this apparatus were Ra = 0.06 um and Rz = 1.62 um.

The adhesives used for bonding the specimens were the earlier mentioned Bonaterm AS BT and Pattex Universal Classic. Bonaterm AS BT is a chloroprene solvent-based adhesive [13]. According to the manufacturer’s instructions it should be applied by spraying. In the case of absorptive materials a second coat of adhesive should be applied on the surface of adherend after the first coat has been allowed to cure for 20 minutes.

Pattex Universal Classic is a polychloroprene adhesive product. According to the manufacturer’s instructions the adherends should be brought together when solvent has been allowed to evaporate from the surface, i.e. after 10–15 minutes from adhesive application [14].

In both cases the surfaces to receive adhesive should be free of any contamination. Adhesive should be evenly spread on the surface and the bond-line thickness should be as small as practicable. Adhesive should be applied on both mating surfaces. The manufacturers’ guidelines require that the pieces should be evenly pressed against each other, yet neither the duration nor the minimum force are specified. The only guidance is given in the Pattex user manual which states that it is the pressure level rather than the duration that matters.

**Figure 3.** Adhesive application station.
The tested adhesives were applied by spraying, using the mechatronic test facility (figure 3) with the test rig comprising: spray gun, compressed air supply system, triaxial (x, y, z) positioning system and support plates for placing the adherends. The adhesive was fed by gravity from the vessel located above the gun. The arrangement of the test piece prior and after application of adhesive is presented in figure 4.

![Figure 4](image)

**Figure 4.** Application of adhesive on the mating surfaces: a) laying the foam, b) foam with adhesive applied on its surface, c) polyamide coated with adhesive.

Before spray application of glue the specimens were cleaned with a solvent and left to rest for a few minutes to make sure that the cleaning solvent has evaporated from the surface. The same process parameters (table 1) were maintained as far as practicable during application of the two adhesives.

| Parameter          | Compressed air pressure (bar) | Spray gun speed of motion (mm min⁻¹) | Nozzle/PUR distance (mm) | Nozzle/polyamide distance (mm) | Pressure application | Duration of pressure application | Spray pattern |
|--------------------|-------------------------------|--------------------------------------|--------------------------|-------------------------------|----------------------|---------------------------------|---------------|
| Value              | 5.5                           | 1873                                 | 60                       | 68                            | manual               | 30                              | round         |

When brought together, the specimens were pressed manually, the same as during the seating production. After application of Pattex the pieces were allowed to rest for 12 minutes before they were brought together. A different procedure was followed in the case of Bonaterm which was applied on the PUR foam in two layers, the second one after 20 minutes after which the components were brought together. This test method was used on 10 specimens, 5 for each type of glue. The specimens are shown in the photos in table 2.

| Specimen coated with Bonaterm AS BT | Specimen coated with Pattex Universal Classic |
|-------------------------------------|---------------------------------------------|
| Before brought together             |                                             |
Table 2 – continue

| Specimen coated with Bonaterm AS BT | Specimen coated with Pattex Universal Classic |
|------------------------------------|---------------------------------------------|
| After brought together, viewed from the polyamide side | After brought together, viewed from the PUR foam side |

3. The test procedures and results

Three main tests were conducted on the prepared specimens: tensile strength of the foam and polyamide and adhesive bond strength by peel test.

3.1. Tensile strength of PUR foam

In this test the specimen is placed in the grips of MTS Insight 50 kN strength tester. Then the tensile load was applied at a rate of 500 mm min⁻¹ until failure. This is in accordance with the guidelines of the standard [11]. The course of the test is presented in figure 5.

![Figure 5. Placing the specimens in the grips and stages of tensioning of a PUR foam specimen.](image-url)
The test was repeated on the five specimens, each time measuring the force and elongation at failure. The maximum breaking force and stress values are given in Table 3. These values are relevant to peel strength determination as they enable estimating the minimum force to be carried by the adhesive bond so that the mode of failure of the specimen is cohesive rather than adhesive.

### Table 3. Force and stress values at which failure of foam specimens occurred.

| Specimen No. | 1     | 2     | 3     | 4     | 5     | Average value |
|--------------|-------|-------|-------|-------|-------|---------------|
| Breaking force (N) | 16.784 | 18.649 | 17.296 | 15.737 | 15.785 | 16.8502 |
| Maximum stress (MPa) | 0.16784 | 0.18649 | 0.17296 | 0.15737 | 0.15785 | 0.168502 |

#### 3.2. Tensile strength of polyamide

Similarly to the foam specimens, the paddle-shaped specimens made of polyamide were placed in the grips of the strength tester and subjected to the tension force applied at a rate of 500 mm min⁻¹ [6] (Figure 6) and this procedure was repeated on the five specimens. The maximum breaking force and stress values are given in Table 4.

### Table 4. Force and stress values at which failure of polyamide specimens occurred.

| Specimen No. | 1     | 2     | 3     | 4     | 5     | Average value |
|--------------|-------|-------|-------|-------|-------|---------------|
| Breaking force (N) | 1277.1 | 1357.3 | 1291.9 | 1454.7 | 1415.6 | 1359.3 |
| Maximum stress (MPa) | 63.86  | 67.86  | 64.6  | 72.73  | 70.78  | 67.97 |

#### 3.3. Adhesive bond strength determined by peel test

The specimens were weighed before and after adhesive application and the amount of adhesive used was calculated. The weighing results are given in Table 5 where the specimens bonded with Bonaterm AS BT are designated Aₙ, and specimens bonded with Pattex Universal Classic are designated Bₙ.

### Table 5. Weights of specimens before and after bonding.

| Specimen No. | A1     | A2     | A3     | A4     | A5     | B1     | B2     | B3     | B4     | B5     |
|--------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Weight before bonding (g) | 16.7   | 16.6   | 16.7   | 16.9   | 16.9   | 16.6   | 17     | 16.7   | 16.9   | 16.6   |
| Weight after bonding (g) | 20     | 20     | 20.2   | 20.6   | 20.5   | 18.7   | 19.3   | 17.9   | 18.7   | 18.8   |
| Difference (g) | 3.3    | 3.4    | 3.5    | 3.7    | 3.6    | 2.1    | 2.3    | 1.8    | 1.8    | 2.2    |
The bonded specimens were placed in the grips of MTS Insight 50 kN apparatus such that the rigid component was held by the fixed jaw. Then the jaws were moved with a speed of 100 mm min\(^{-1}\) [12]. The test was continued until failure of the specimen (figure 7). The stages of peeling of the foam are shown in figure 8.

![Figure 7. View of the specimen held in the grips of the strength tester.](image)

![Figure 8. Stages of the foam peeling process.](image)

In the case of two specimens bonded with Pattex the foam failure occurred in the jaws (figure 9a) rather than in the bond area as in the cases shown in figure 7 and figure 8. This can be attributed to strengthening of the foam by the adhesive since these specimens started to peel also at the adhesive bond yet did not break where adhesive extended beyond the joint border which can be seen in figure 9b and figure 9c. The broken specimens after tensile test are shown in figure 10.

![Figure 9. Specimens that failed at grips: a) breaking point of specimens No. B1 and B4, b) failure initiation point of specimen B1, c) view of joint of B4 specimen.](image)
Figure 10. Broken specimens after the peel test.

The parameters recorded during the tests were the force and elongation. The graphs in figure 11 and figure 12 present the force vs. elongation curves for the two tested adhesives. The forces and breaking stress values are given in table 6.

Table 6. Forces and maximum stress values for specimens bonded with Bonaterm (A) and Pattex (B).

| Specimen No. | A1   | A2   | A3   | A4   | A5   | B1   | B2   | B3   | B4   | B5   |
|--------------|------|------|------|------|------|------|------|------|------|------|
| **Breaking force (N)** | 24.57 | 21.87 | 23.46 | 25.51 | 19.11 | 30.31 | 21.14 | 22.23 | 27.59 | 17.25 |
| **Breaking stress (MPa)** | 0.095 | 0.084 | 0.09 | 0.098 | 0.074 | 0.117 | 0.08 | 0.086 | 0.106 | 0.066 |

Figure 11. Breaking forces of specimens bonded with Bonaterm AS BT.
Figure 12. Breaking forces of specimens bonded with Pattex Universal Classic.

4. Analysis of results and conclusions
The tensile strength tests conducted as part of this study on specimens made of PUR foam and polyamide enabled determination of the weaker material and the breaking force value. As it can be seen, and in line with expectations, the tested foam was found to be significantly weaker of the two materials. The tensile strength of the tested foam was determined at which the average breaking stress is 0.169 MPa. The photos taken during the peel test show compression and kinking of the tested foam at the transition point (figures 7, 8, 10). This could be the cause of the smaller peel strength of foam. Two specimens which failed at the grip have uneven layer of glue at the joint termination. This could increase the specimen strength, resulting in failure of the specimen at the grip. Higher values of breaking stress were recorded in this case, as compared to the other specimens. It can also be seen that despite coating with adhesive the foam also started to peel at bare spots. In the other cases failure occurred beyond the limits of adhesive layer.

There is a substantial variation of breaking force values. The problem of measurement accuracy can be attributed to small force levels to be measured. Note that the strength tester used in this study has a measuring range up to 50 kN with measurement error in the region of few newtons. For this reason, any future tests to determine the strength parameters of foams should be made with a test machine offering a higher accuracy of measurement of small forces.

The problems encountered in the application of adhesive included its varying viscosity, problem with determining the solvent evaporation rate and lack of manufacturers’ guidance concerning nozzle distance and other spraying process parameters. The differences in application of different kinds of adhesive can be seen on the photos in table 2 showing the samples with applied glue, ready to be brought together. These differences are caused primarily by the differences in viscosity of different adhesives applied at the same pressure and distance from the surface. Due to its smaller viscosity Bonaterm spreads more sideways, this resulting in a smaller amount of glue reaching the adherend surface. This is more evident on polyamide specimens since foam absorbs the adhesive instantly due to its high absorbing capacity. Moreover, upon application of the second coat of Bonaterm the foam has become saturated to a degree at which it has lost its elastic properties (figure 13).
Moreover, application of the second layer of adhesive increased its consumption and the specimen weight as a consequence (table 5). The difference between the heaviest and the lightest specimens was 0.4 g for Bonaterm and 0.5 g for Pattex which indicates low repeatability of the adhesive layer thickness.

In the peel test the force increased proportionally to elongation. The breaking stress variation can be attributed to the depth and distance of penetration of glue beyond the bond limit. Application of pressure to foam resulted in its displacement in relation to polyamide which, however, could not be corrected due to instant bonding of adhesive. Moreover, such corrections are discouraged by the manufacturer as they can considerably reduce the bond strength and introduce bubbles into the adhesive layer.

In each of the ten conducted tests the adhesive bond was stronger than the foam. Finally, we can confirm that the foam was the weakest element of the joint and cohesive failure occurred in its body [15]. Note that glues performed well and did not separate from polyamide despite small surface roughness of the polyamide used in the tests.

Unfortunately, solvent-based glues are substances harmful to health which justifies research efforts to automate the process, yet this research must include tests involving the use of these harmful solvents. What we know by now is that particular attention must be paid to the viscosity of adhesive which determines several other parameters of the spraying process, including the required pressure of compressed air and the distance from the adherend surface. Also the absorption rate and surface roughness of adherends are relevant factors because of the risk that the adhesive can be pushed away from the smooth surface of adherend when the spraying pressure is set too high which was observed on polyamide specimens.

Therefore, there are grounds to question the adhesive manufacturer’s recommendation of spraying technique as the preferred method of adhesive application.

5. References
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