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Testing of Glued Joints on 3D Printed Flexible Materials Made by FFF Technology

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Abstract. The article deals with testing of glued joints of plastic parts manufactured by 3D printing. In the first section of this article is introduction of elastic plastic materials used for 3D-printing, followed by an overview of selected glues used to glue plastic samples. The glued plastic samples were tested on tensile testing machine accordingly to standard DIN EN 1465 (standard for testing of the glued samples). For each type of glued joint, the maximal and minimal breaking force, the dependence of loading force on displacement and the maximal and minimal stress are evaluated. The aim of this article is to evaluate and compare tensile tests of glued joints for different types of glues used on different types of plastic materials.

Introduction

3D printing is a process of making three dimensional solid objects from a digital file. This technology is based on adding thin layers of material on top of each other in order to create desired solid object. [1,2]

There are many advantages to this method of creating 3D objects (speed, price, shape diversity, weight, etc), but also some disadvantages as well. One of them being a limited print area of 3D printers to make objects in. Therefore, bigger objects must be divided into several smaller parts that fits into that print area. The glue method is offered to connect individual parts.

This paper deals with testing of the strength of glued joints made by using various glues, where the glued parts are made from flexible plastic TPE (Thermoplastic elastomer). Research done in this area shows, that the glued joints between flexible plastics are not stronger than the plastic material itself. While testing, all glued samples made from TPE material broke in the glued joint (the glued surfaces separated from each other). This can be caused either by bad adhesion of the glue to the surface, or by high elasticity and elongation of the TPE material compared to the hardened adhesive layer that has lower elasticity, thus when the material is elongated the adhesive layer tears itself off the surface. [2-6].

Description of samples – Each glued sample is marked by two letters. First letter represents material, from which the sample is made. Second letter is the type of adhesive glue used to glue parts of the sample together.

First letter (type of material):

A) Fiberflex 30D.

B) TPE 88

Second letter (type of adhesive glue):
G) PECKALEP GUMMI
L) LOCTITE 4850
B) BLACK BOLT
Z) ZAP-RT CA

Samples are made of two identical printed parts of dimensions 70 x 25 x 1 mm (length x width x thickness) glued together.
Parts were connected by the glue across all their width in length of 12.5 mm see at Fig. 1 (blue area marks the glue), which corresponds to DIN EN 1465 (the standard for testing glued samples by tensile test) [3].

Surface preparation and gluing – The top surface of the test samples was treated before gluing. The surface was first mechanically sanded with a medium-thick sandpaper and then subsequently cleaned with acetone and degreaser. After that, the samples were manipulated only with gloves, to prevent smearing of surface. A thin layer of glue was applied on the samples and then the two parts were pressed together as shown at Fig. 1. [7, 8]

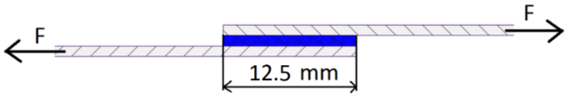

Fig. 1: Example of bonding samples

A fixture for precise sample placement during gluing was created to make sure the parts of the sample were always glued in the same position.

Tensile test
All samples were subjected to a tensile test on the Testometric M500/50CT machine (Fig. 2) in the laboratory. The load force F was gradually increased until the glued joint failed and the samples separated. The load force F (N) and elongation Δ_L (mm) were recorded. The pic. 2 shows ripped sample after tensile test. The sample is clamped in testing device.

Fig. 2: Sample clamped in to testing device after tensile test,

While testing, sample is loaded to tension, whereas the glued joint is loaded to shear. Due to a little misalignment of glued parts, some load to bending occurs. This phenomenon causes removal of adhesive glue, but because in this case misalignment is minimal, this influence can be neglected.

Results

Material Fiberflex 30D (A thermoplastic elastomer with a hardness of 30D Shore)
Dependence of the loading force on sample deflection for material Fiberflex 30D is shown in Fig. 3, 4. Five samples tested for each group (AG, AL, AB, AZ).

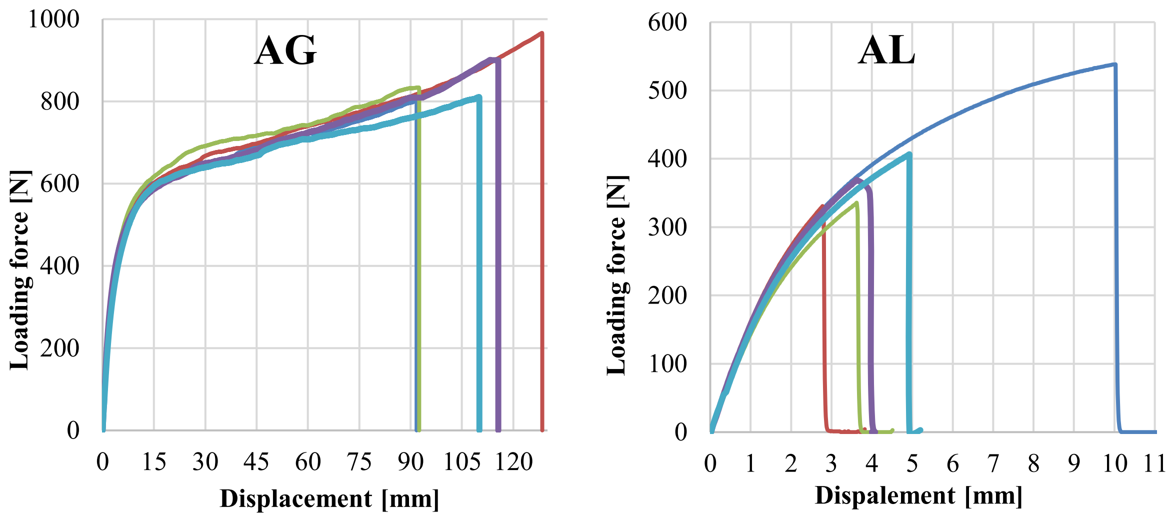

Fig. 3: Measurement – Dependence of loading force on displacement:
(a) Samples marked AG, (b) Samples marked AL

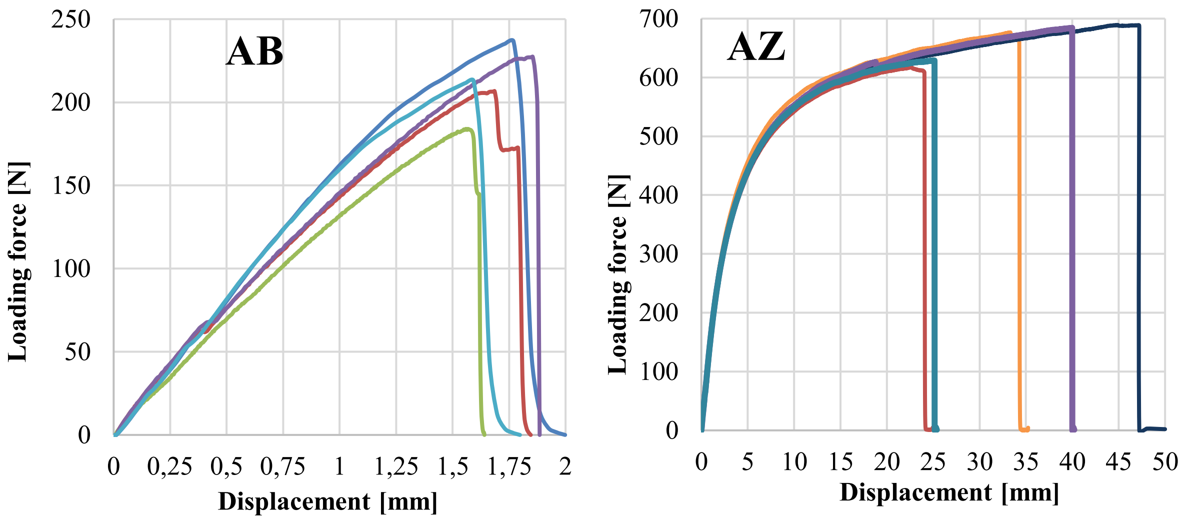

Fig. 4: Measurement – Dependence of loading force on displacement:
(a) Samples marked AB, (b) Samples marked AZ

Material TPE 88 (A flexible material like a rubber, the designation TPE 88 indicates the degree of elasticity). Dependence of the loading force on sample deflection for material TPE 88 is shown in Fig. 5, 6. Five samples tested for each group (DG, DL, DB, DZ).

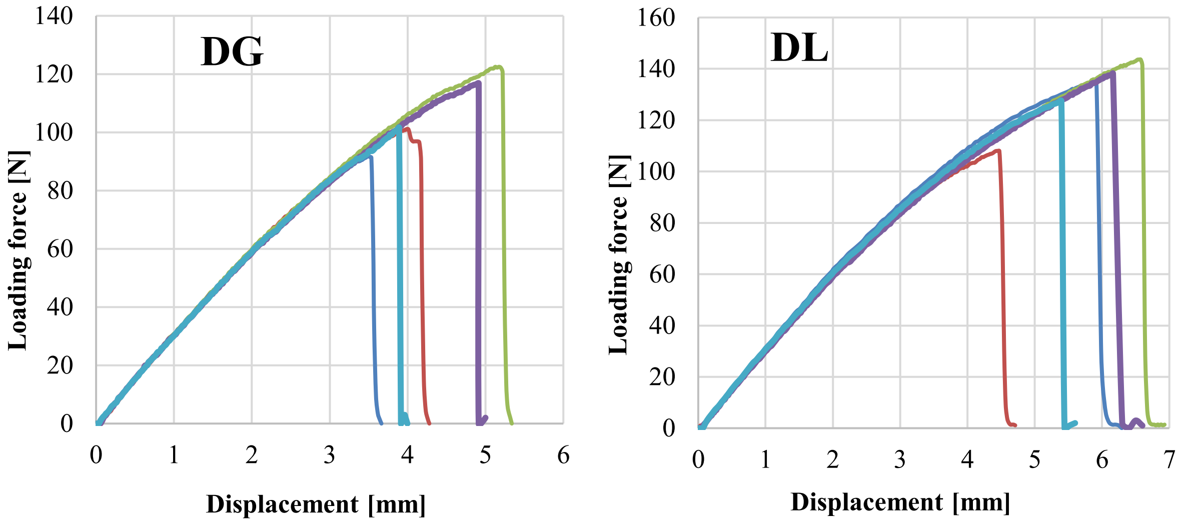

Fig. 5: Measurement – Dependence of loading force on displacement:
(a) Samples marked DG, (b) Samples marked DL

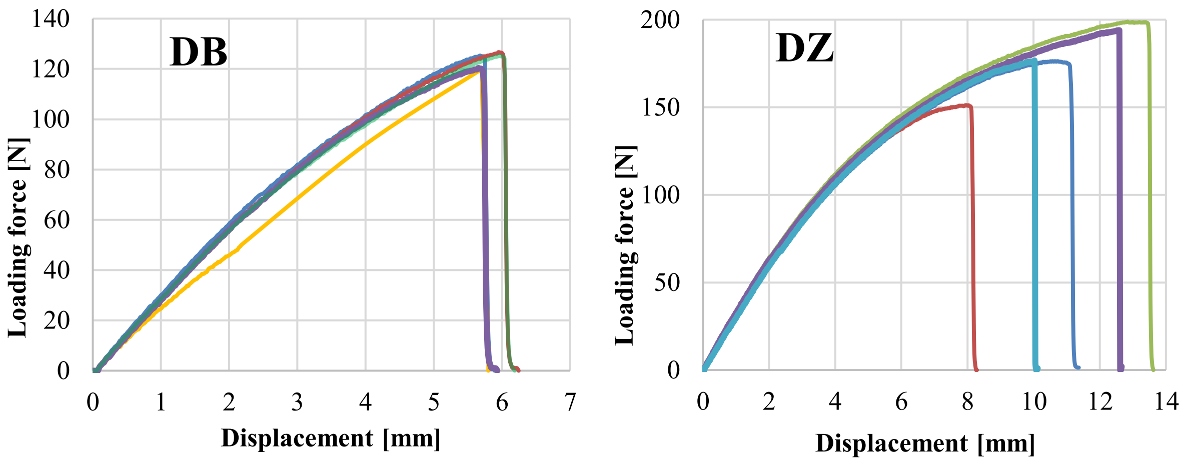

Fig. 6: Measurement – Dependence of loading force on displacement:
(a) Samples marked DB, (b) Samples marked DZ

The maximal shear stress calculated as

$$\tau_{S_{MAX}} = \frac{F_{MAX}}{S} = \frac{F_{MAX}}{a \cdot b} \tag{1}$$

the minimal shear stress calculated as

$$\tau_{S_{MIN}} = \frac{F_{MIN}}{S} = \frac{F_{MIN}}{a \cdot b} \tag{2}$$

where a is with of sample (25 mm), b is length of glued joint (12,5 mm) and F_{MAX}, F_{MIN} is maximal and minimal loading force.

Table 1: Comparison of test results

Mark of sample [-]	Maximal force F_{MAX} [N]	Minimal force F_{MIN} [N]	Stochastic definitions force [N]	Maximal Shear Stress $\tau_{S_{MAX}}$ [MPa]	Minimal Shear Stress $\tau_{S_{MIN}}$ [MPa]	Mean value of Shear Stress [MPa]
AG	**966**	**802**	$\mathbf{863^{+103}_{-61}}$	**3.09**	**2.57**	**2.76**
AL	538	330	396^{+142}_{-66}	1.72	1.06	1.27
AB	237	184	213^{+24}_{-29}	0.76	0.59	0.68
AZ	689	616	657^{+32}_{-41}	2.2	1.97	2.1
DG	122	92	107 ± 15	0.39	0.29	0.34
DL	144	108	131^{+13}_{-23}	0.46	0.35	0.42
DB	127	120	124^{+7}_{-4}	0.41	0.38	0.4
DZ	**199**	**151**	$\mathbf{179^{+20}_{-28}}$	**0.64**	**0.48**	**0.57**

The next Fig. 7 (a), (b), shows box plots of maximal and minimal shear stress. The individual boxes show the material and type of glue used on the sample, compared to maximal a minimal shear stress needed to rip the sample.

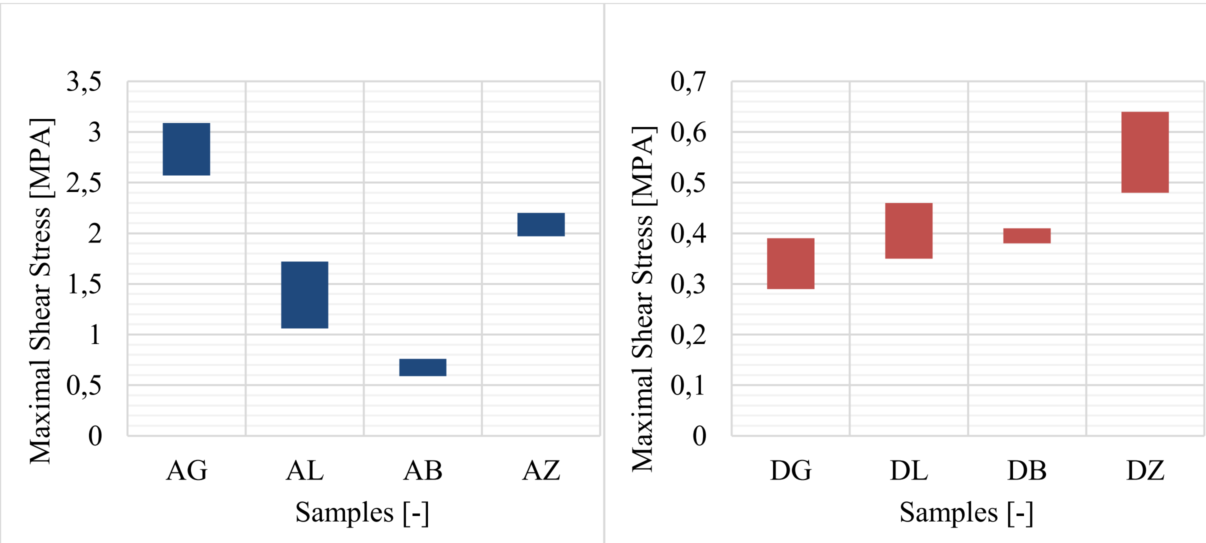

Fig. 7: Boxplots of maximal shear stress: (a) Material Fiberflex 30D, (b) Material TPE80E

Conclusions

This paper deals with gluing flexible plastic TPE and testing the glued joint. The results of tensile tests show the strength of glued joints of individual glue types used. The choice of glue type, depending on the material, leads to a bigger strength of glued joint.

Peackalep Gummi (marked G) is the most suitable for gluing parts made of material Fiberflex 30D (marked A). Five samples were created for each type of glue. In the worst case the glued joint broke at load of 802 N (minimum force to break sample) see at Fig. 3(a) and

Tab. 1. In the best case the glued joint broke at load of 966 N was needed, see at Fig. 3(a) and Tab. 1. According to equations (1) and (2), the maximal and minimal shear stress was determined, see. Tab. 1. The maximal and minimal shear stress for each type of glued joint are clearly displayed in the boxplots, see. Fig at 7(a). The worst type of glue for this material is Black bolt (marked B), glued joint made with this type of glue broke under a load of 184-237 N, see at Fig. 4(a). The results of other glued joints are shown in Tab. 1.

Zap-RT CA (marked Z) is the most suitable for gluing parts made of material TPE 88 (marked D). Five samples were created for each type of glue. In the worst case the glued joint broke at load of 151 N (minimum force to break sample) see at Fig. 6(b) and Tab. 1. In the best case the glued joint broke at load of 199 N, see at Fig. 6(b) and Tab. 1. According to equations (1) and (2), it was determined maximal and minimal shear stress, see. Tab. 1. The maximal and minimal shear stress for each type of glued joint are clearly display in the boxplots, see at Fig. 7(b). The worst type of glue for this material is Peckalep Gummi (marked G), glued joint made with this type of glue broke under a load of 92-122 N, see at Fig. 5(a). The results of other glued joints are shown in Tab. 1.

Acknowledgement

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