

## ADHESION MEASURING METHOD OPTIMIZATION IN REINFORCED COMPOSITES

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***Abstract:** The objective of the current study is to analyze and modify the adhesion processes between the glass-fiber reinforcement layer and acrylic sheet and to find out the optimal adhesion measuring methods depending on the bending strength, reinforcement layer concentrations and plastic composite material parameters (dimensions, wall angles, edge radiuses and connection methods). The experimental tests with different glass-fiber reinforcement concentrations, testing part design and acrylic material heating temperatures have been performed. Different well known methods have been analyzed for finding out the optimal adhesion measuring method. For optimal selection of the adhesion measuring process and the adhesion area the optimization model has been proposed. There have been tried to find out the max Tensile Force, optimal adhesion area and testing part design to minimize acrylic sheet brokering. The Finite Element Analysis simulation has performed with optimal adhesion area values to verify the prediction accuracy of a surrogate model.*

*Keywords: adhesion processes, large composite plastic products, glass-fiber reinforced composites, finite element analysis.*

### 1. INTRODUCTION

The increasing competitiveness in markets highlights the importance of rapid product development, high quality products, productivity, optimal price levels, multi-company collaboration and predictability. The manufacturers have to update and

improve their product development, production process and product quality to maintain their places in the market. To improve their ability to innovate, get products to the market faster than the competitors and reduce errors [<sup>1,2</sup>].

In different industries like whirlpool, aerospace, plastic boat, composite barrel and car body component building industries the final product quality depends on the composite plastic parts. In those fields the large composite plastic parts are visible and because of that they will determine the final product sales success in large extent [<sup>3,4</sup>].

There have been analyzed a large composite plastic bathtub (dimensions 2300 mm in length, 900 mm in width and 800 mm in depth). The production of the bathtub has been made in two main stages. The first stage is vacuum forming of the inner shell acrylite FF0013 Plexiglas. The second stage is applying the reinforcement layer to the vacuum formed shell. The reinforcement consists of polyester resin with randomly oriented short glass fibers. Concentration of curing agent Methyl Ethyl Ketone Peroxide (MEKP) 0.8%, the epoxy resin 64.1% and glass-fiber 35.1%. There was developed a surrogate model consisting of finite element method (FEM) and artificial neural network (ANN) to find out the optimal wall thickness distribution for a thermoformed and glass-fiber polyester reinforced part [<sup>5,6,7</sup>].

There could be some abnormalities in the reinforcement process, depending on the weak adhesion between the reinforcement layer and the acrylic sheet. There could be some open spaces between those two

layers depending on the vacuum forming temperatures, product parameters (wall angle, edge radiuses, etc), reinforcement layer concentrations, material thicknesses, glass-fiber orientations and concentrations [8,9]. Some samples of the weak adhesion are brought out in Fig. 1 and Fig. 2.

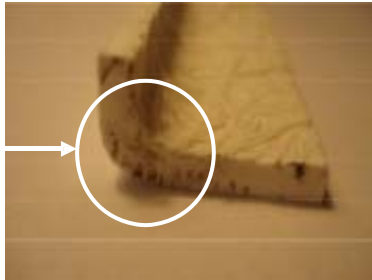


Fig. 1. The sample of the open space in corner

Because of the weak adhesion between two layers there could be defects in final products. In Fig. 3. is brought out defective bathtub. After cleaning the bathtub acrylics sheet broke down, because there were open space between two material layers.



Fig.2. The sample of the weak adhesion

To avoid those issues brought out in Fig.1-Fig.3. it is very important that we can manage the adhesions processes between different composite layers. Thus it is important to find out suitable adhesion measuring method.



Fig.3. Broken bathtub

## 2. ADHESION MEASURING METHOD OPTIMIZATION

Different adhesion measuring methods can be divided into two categories: destructive and nondestructive. More is used destructive class, where a loading force is applied to the coating in some specified manner and the resulting damage is subsequently observed. Nondestructive methods typically apply a pulse of energy to the coating system and then try to identify a specific portion of the energy that can be assigned to losses occurring because of mechanisms operating only at the interface. In destructive test class there are many different types of well known test methods like tensile test, peel test, tape peel test, indentation bonding test, self loading test, scratch test, blister test, beam bending test etc [10,11].

To find out optimal adhesion measuring method we have to analyze different well known methods and find out the effective one. After the analysis of different methods tensile testing was selected. The main issue was to find out the optimal design of the test part, optimal thickness for the glass-fiber reinforcement layer, optimal adhesion area and to avoid additional bending strengths and stresses to get the reliable results.

In the beginning we tried to find out the optimal test part design and adhesion area, depending on the materials conditions and parameters. The selection of the adhesion area parameters are crucial. Firstly when the area is too big, then the acrylic material will break down and we can't measure the correct force. Secondly when the area is too small then glass-fiber reinforcement layer will be removed too quickly and we will measure too low force and wrong adhesion. Because of that it is important to find out the optimal adhesion area to get the reliable measurement data. There have been simulated and tested different shapes of test parts [12] and some of the samples are brought out in Fig.4.

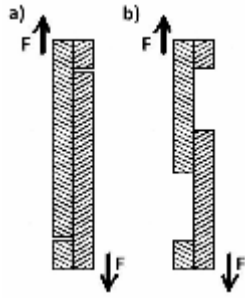


Fig. 4. The samples of the test part

There have been milled two grooves into the acrylic sheet and reinforcement layer to separate those two layers. Several tests have been made, but the result was the same – acrylic material broke down. This was caused by too strong connection, too large adhesion area and properties of the materials. Some samples of the test results are brought out in Fig.5.



Fig. 5. The acrylic material break down

To optimize the adhesion area and testing part design the optimization model has been developed using FEM software HyperWorks. The optimal adhesion area has been determined and the results were validated against experimental test to control the reliability of the existing model. The first step of the tensile strength FEM simulation is shown in Fig.6 (the stress parameters are given in MPa).

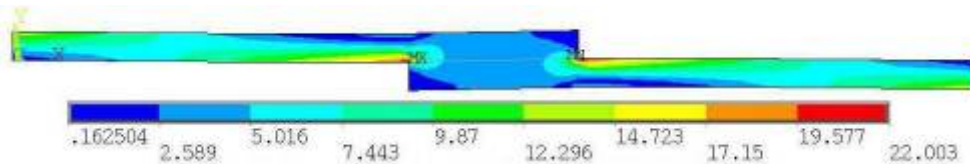
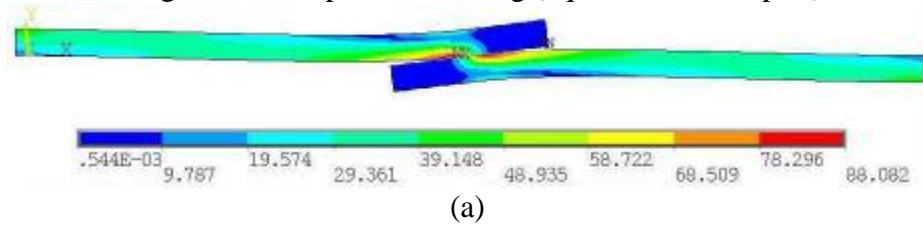
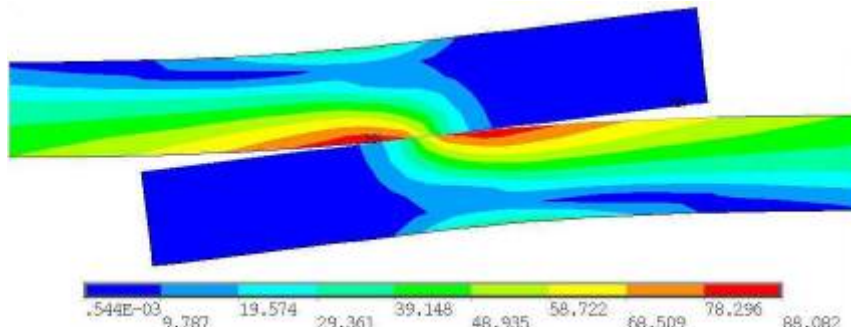


Fig. 6. First step of the loading (equivalent stress plot)



(a)



(b)

Fig.7. Final step of the equivalent stress plot (a) and detailed view (b).

The final step in tensile test (a) and more detailed view (b) of the equivalent stress plot is shown in the Fig. 7. This was the final step, when the tensile test continued then in the next step the materials were disjointed completely. Modified testing part is brought out in Fig.8.

In the FEM optimization there was found out the critical bending stresses during the test process. To avoid the additional bending different test part design and connection methods were developed.



Fig. 8. Modified testing part

In Fig. 9 are brought out some types of the testing parts. Streaked details are additional supporting bars, which help to avoid the additional bending. To test the reliability of the testing part with additional bars different FEM simulations were done. In Fig. 10 is brought out the deformation plot

in the final stage with mm. In Fig.11. is brought out removed parts after the test.

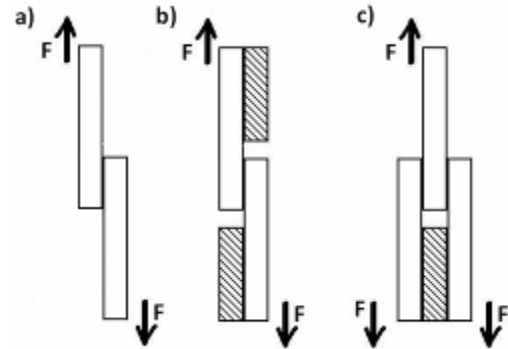


Fig. 9. Different design of the testing part

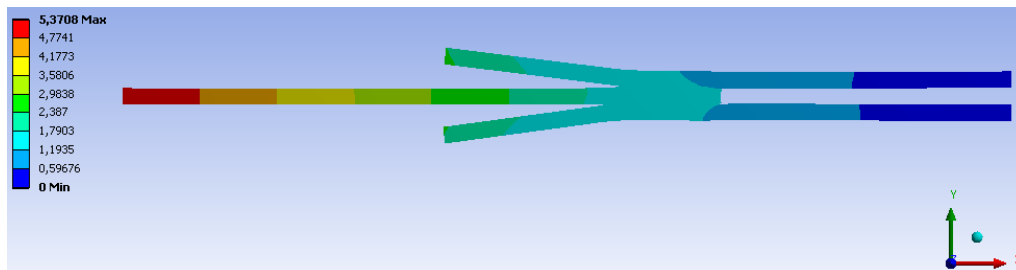


Fig. 10. Deformations in the final stage



Fig. 11. Removed parts after test

### 3. ANALYSIS OF MEASUREMENT RESULTS

For measuring the glass-fiber reinforcement layer and the acrylic sheet adhesion lot of different experimental tests have been done. The ratio of the polyester resin and fibers is kept constant, but the concentration of Methyl Ethyl Ketone Peroxide (MEKP) is varied from 0.8% up to 2%. Evidently, the ratio of the polyester resin and MEKP has significant influence on curing time and also on mechanical properties (e.g. modulus of elasticity, tensile strength) of the composite [12]. There were also varied

the glass-fiber concentration and lengths in the reinforcement layer and tested three different group (in group A length of the glass-fiber is 5 mm, B – 10 mm and C- 15 mm) also similar concentration change between the groups) of tested parts. Some results of the measurements are brought out in Table 1 and Fig.12. In Fig. 13 is brought out summarized Max Force in three group.

In Table 1 and Fig. 12 are brought out some sample results of the experimental tests. Those test are made with three groups of materials (A, B and C), which are different of the glass-fiber concentrations and length. Values which are brought out are the mean values of the different tested groups. There were also made different test wher varied: the MEKP concentration, acrylic material was heated or not, reinforcement layer with and without of the glass-fibers, reinforcement layer thickness and etc [12].

From the experimental test, there were found out that there are connection

between glass-fiber concentration and fiber reinforcement layer and the acrylic length to the adhesion between the glass-sheet.

Specimen	Thickness	Width	Yield	Yield Force	Elong at Yield	Max Force	Tensile strength	Elonga- tion
	mm	mm	MPa	N	%	N	MPa	%
A_11	18	6x2	36,67	1760	16,2	1760	36,67	16,2
A_21	18	7x2	34,58	1660	12,9	1660	34,58	12,9
A_51	18	6x2	33,42	1604	14,3	1604	33,42	14,3
A_61	18	6x2	33,83	1624	12,3	1624	33,83	12,3
B_11	18	7x2	40,50	1944	16,5	1944	40,50	16,5
B_31	18	7x2	36,79	1766	13,8	1766	36,79	13,8
B_51	18	7x2	41,77	2005	13,1	2005	41,77	13,1
B_61	18	7x2	44,11	2118	16,3	2118	44,11	16,3
C_11	18	6x2	46,51	2233	13,5	2233	46,51	13,5
C_21	18	6x2	51,20	2458	14,8	2458	51,20	14,8
C_41	18	7x2	42,86	2058	14,7	2058	42,86	14,7
C_71	18	7x2	54,08	2596	19,6	2596	54,08	19,6

Table 1. Results of the experimental test

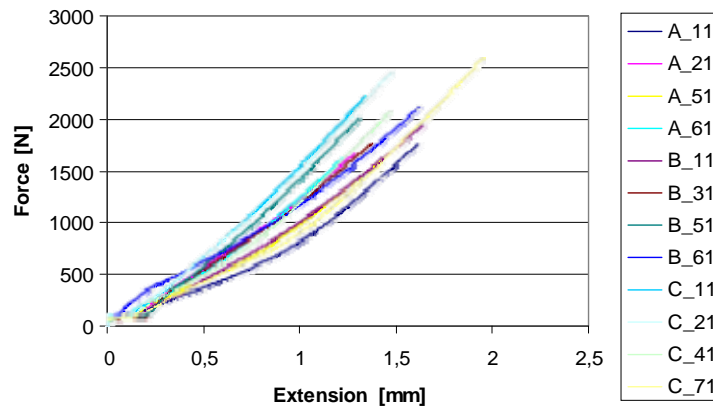


Fig. 12. Force extension graph

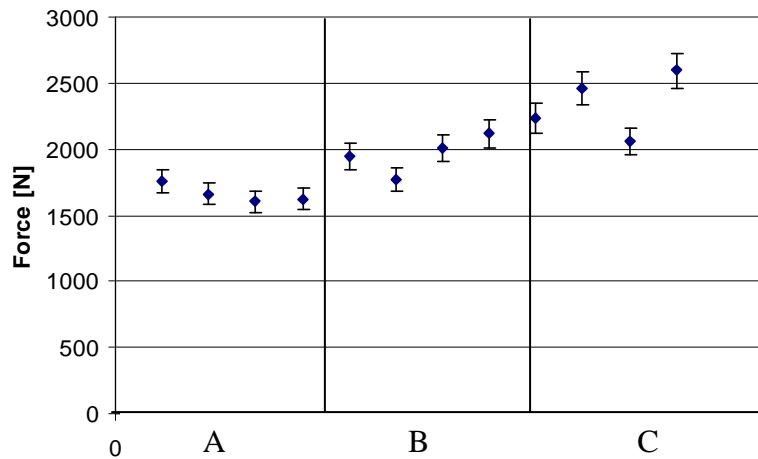


Fig. 13. Summarized Max Force in groups

#### 4. CONCLUSIONS

The adhesion processes between the glass-fiber reinforcement layer and acrylic sheet were analyzed, the optimal adhesion measuring methods were selected.

The optimization model has been developed for determining optimal adhesion area and testing part design. This procedure includes design of experiment, FEM simulation and experimental validation of reliability of the model.

A number of experimental tests have been made with different glass-fiber reinforcement concentrations, acrylic sheet heating temperatures and adhesion area parameter variations.

The results of the experimental tests can be used as the base for the future glass-fiber reinforcement layer and acrylic sheet adhesion optimization processes.

#### 5. ACKNOWLEDGEMENTS

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