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OPTIMAL ADHESION MEASURING METHODS OF THE GLASS-FIBER REINFORCEMENT LAYER

Karjust, K.; Pohlak, M. & Majak, J.

Abstract: *The objective of the current study is to analyze the adhesion processes between the glass-fiber reinforcement layer and acrylic sheet to find out the optimal adhesion measuring methods depending on the reinforcement layer concentrations and plastic composite material parameters (dimensions, wall angles, edge radiuses).*
The experimental tests with different glass-fiber reinforcement concentrations, material heating temperatures and adhesion area variations have been considered. For finding out the optimal adhesion measuring method there have been analyzed different well known methods and tried to find out the effective one.
Keywords: Large composite plastic products, vacuum forming technology, short glass-fiber reinforcement, adhesion.

1. INTRODUCTION

Modern day enterprises are confronted by challenges arising from continuous innovations, global collaborations, and complex risk management. The increasing competitiveness in global market highlights the importance of rapid product development, design quality management, productivity, optimal price levels, multi-company collaboration and predictability. The manufacturers is under the pressure 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. The performance of the products and processes are simulated in a computer, to determine if it will perform as desired. Any undesirable conditions are modified, and the new design is simulated again. The manufacturers have also been continuing to improve their product development process, production and product quality management abilities [1,2,3].
In many industries (whirlpool, portable spa, aerospace, health treatment capsule, plastic boat, and car body component building industries) the final product quality depends on composite plastic parts. In those industries the large composite plastic parts are visible and that’s why they will determine the final product sales success in large extent. It is important to manufacture and develop those parts with quality as good as possible. Also large parts need more storage and handling spaces and it is very important to organize effectively the whole technology route depending on the manufacturing, lead times, production capacity and market requirements [4,5,6,7].
One sample of the large composite plastic parts is composite 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 for peroxide 0,8%, the epoxy resin 64,1% and glass-fiber 35,1%. The reinforcement layer is applied by manual short fiber/polyester resin spraying. Thus, the thickness of the final layer can vary and it can be controlled by the operator [8].

The final shell thickness in different areas may differ significantly in the vacuum forming process, so this has to be taken into account in structural analysis of the product. For modeling and structural analysis of derivative products CAE (HyperWorks) and CAD (Siemens NX) systems are used. 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 [[9,10]].

There could be some abnormalities depending on the adhesion between the reinforcement layer and the acrylic Plexiglas. Depending on the vacuum forming temperatures, product parameters (wall angle, edge radiuses, etc), reinforcement layer concentrations, material thicknesses, glass-fiber orientations, concentrations and acrylic types there could be some open spaces between those two layers [[11,12]]. Some samples of the defective adhesion between acrylic and glass-fiber reinforcement layer are brought out in Fig.1 and Fig.2.

Fig. 1. The sample of the defect in corner

Fig.2. The sample of the defective adhesion

These defects will make the product weak against the loading (pressure and weight). Thus it is very important to control the adhesion of the glass-fiber reinforcement layer and plastic shell. In order to achieve the effective control and results the adhesion measuring method should be improved.

2. OPTIMIZATION OF THE ADHESION MEASURING METHOD

Adhesion measuring methods can be divided into two categories: destructive and nondestructive. Generally is used destructive class, by which 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 [[13,14,15,16]].

For finding out the optimal adhesion measuring method for the glass-fiber reinforcement layer, there have been analyzed different well known methods and tried to find out the most effective one, depending on the concrete materials, structure and products shapes. After the analysis of different methods tensile testing was selected. The main issue was to find out the optimal shape for the test part, optimal thickness for the glass-fiber reinforcement layer, optimal adhesion area to avoid additional bending and stresses for getting the reliable results.

In the beginning we tried to find out the optimal adhesion area, depending on our conditions and material parameters. On the one hand, when the area is too big, then the acrylic material will break down and we can’t measure the correct force. On the other hand, when the area is too small then glass-fiber reinforcement layer will be removed too quickly and we will measure too low force. Because of that it is very important to find out the optimal adhesion area to get the reliable measurement data. Sample of the test part is brought out in Fig.3. There have been milled two grooves into the acrylic and reinforcement layer to separate those two layers.

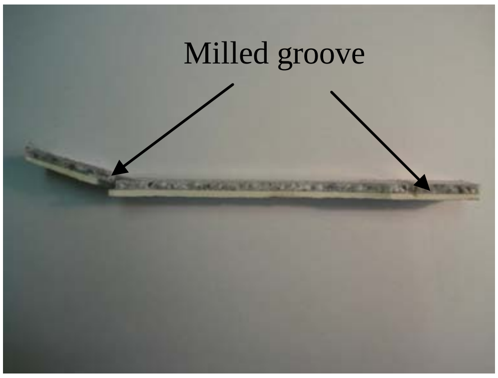

Fig. 3. The sample of the test part

There have been made several test, but the result was the same – acrylic material break down. This was caused because of the too strong connection, too big adhesion area and properties of the materials. One sample of the test results is brought out in Fig.4.

Fig. 4. The acrylic material break down

In the experimental optimization phase we started to minimize the adhesion area. One sample of the test is brought out in Fig.5 where the area was still too large and the material braked down, but the measured force was close to the optimal force for that connection and material. After the test and analysis there were found out the optimal cut-out and adhesion area dimensions, which are brought out in Fig. 6.

Fig. 5. Cracked acrylic material

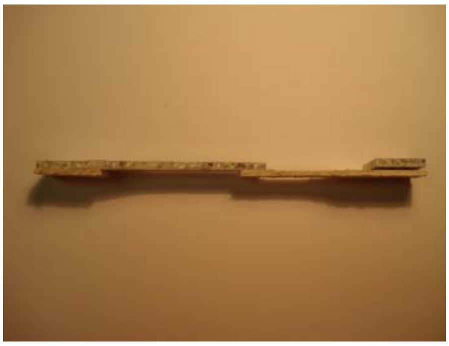

Fig. 6. Optimal cut-outs and adhesion area

The next constraint in addition to the adhesion area what has to be taken into account was bending. For describing bending process Fig.7. is brought out.

Fig. 7. Material bending before cracking

The problem is that the test material (acrylite FF0013 Plexiglas) will bend near the connection area and after that acrylic material will crack. To avoid the material bending and additional forces to the materials, we optimized the testing part. The adhesion area was the same, but the length of the testing parts were shorter. In Fig.8 is brought out the final testing shape with its adhesion area and in Fig.9 it is connected together with the supporting parts. In Fig. 10 is brought out the sample of the disjointed part. We can see that the acrylic material didn't crack and the two parts were disjointed perfectly.

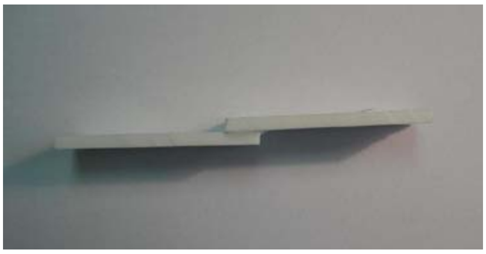

Fig. 8. Optimized testing part

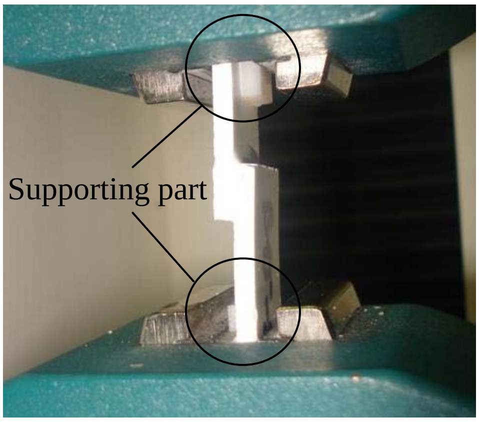

Fig. 9. Testing and supporting parts

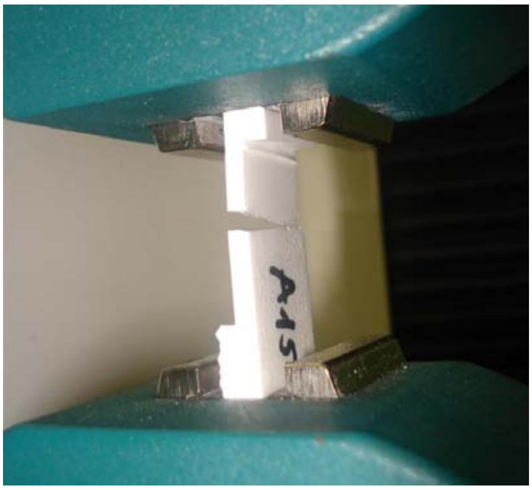

Fig. 10. The sample of the disjointed part

3. ANALYSIS OF MEASUREMENT RESULTS

For measuring the glass-fiber reinforcement layer and the acrylic sheet adhesion, many 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. Some results of the measurements are brought out in Table 1 and Fig.10.

Specimen	Thickness	Width	Yield	Yield Force	Elong at Yield	Max Force	Tensile strength	Elongation
	mm	mm	MPa	N	%	N	MPa	%
A11-6-3	18	6	4,5	486	7,22	486	4,5	7,22
B11-7-3	19	7	4,17	554	14,9	554	4,17	14,9
B11-7-K2	18	7	3	327	3,92	327	3	3,92
B15-5	17	7	8,1	964	9,77	964	8,1	9,77
A15-5	19	9	5,92	1013	9,29	1013	5,92	9,29
B19-4	18	7	8,07	1017	8,46	1017	8,07	8,46
A19K-4	18	6	8,29	896	7,82	896	8,29	7,82
B10-2	19	6	7,44	848	6,39	848	7,44	6,39
A15K-3	19	9	6,32	1081	11,3	1081	6,32	11,3

Table 1. Results of the experimental test

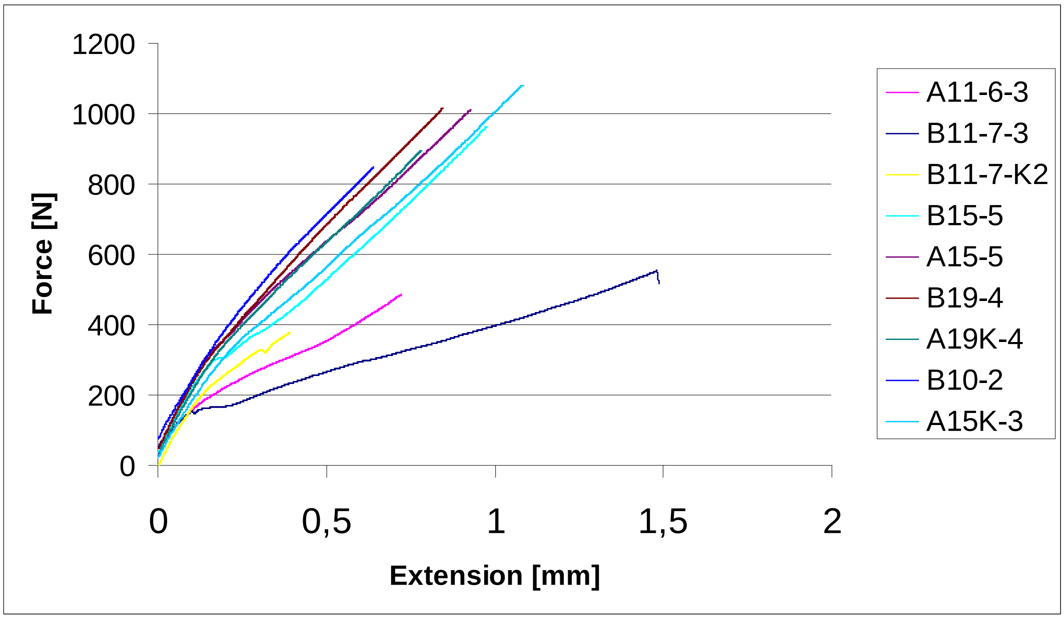

Fig. 11. Force extension graph

In Table 1 and Fig. 11 are brought out some sample results of the experimental tests. Those test are made with different group materials. Values which are brought out are the mean values of the different tested groups. There were tested nine different groups of materials and in each group were ten testing parts. Different parameters were varied: the MEKP concentration, acrylic material was heated or not, reinforcement layer with and without of the glass-fibers, reinforcement layer thickness and etc.

From the experimental test, there were found out that the adhesion between the glass-fiber reinforcement layer and the acrylic sheet depends on the adhesion area parameters, additional forces and bending, acrylic sheet material conditions (cracks and micro defects), MEKP concentrations (better adhesion when the concentration is higher 1.5 or 2.0%), glass-fiber positions and orientations in reinforcement layer (when the glass fiber is close to the acrylic sheet, then it makes the adhesion weaker, because the resin and MEKP connection is bad). On the other hand there was found out no change of the adhesion when acrylic sheet was heated or not. Also there was no change when in the reinforcement layer has optimally oriented glass fibers or not.

4. CONCLUSIONS

The objective of the current study is to analyze the adhesion processes between the glass-fiber reinforcement layer and acrylic sheet, and to find out the optimal adhesion measuring methods depending on the reinforcement layer concentrations and plastic composite material parameters (dimensions, wall angles, edge radiuses).

For finding out the optimal adhesion measuring method for the glass-fiber reinforcement layer, there have been analyzed different well known methods and found out the effective one, depending on the used materials, structure and products shapes.

There have been made several experimental tests with different glass-fiber reinforcement concentrations, acrylic sheet heating temperatures and adhesion area parameter variations. There were found out that the adhesion between the glass-fiber reinforcement layer and the acrylic sheet depends on the MEKP concentrations (better adhesion when the concentration is higher 1.5 or 2.0%), glass-fiber positions and orientations in reinforcement layer.

The results of the experimental tests are used as the basic work for the future glass-fiber reinforcement layer and acrylic sheet adhesion optimization processes.

5. ACKNOWLEDGEMENTS

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7. CORRESPONDING AUTHORS

Associate Professor Kristo Karjust, Senior Research Scientists Meelis Pohlak and Jüri Majak, Department of Machinery,
Tallinn University of Technology,
Ehitajate tee 5, Tallinn, 19086, Estonia
E-mail:kristo@staff.ttu.ee