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LAMINATE OBJECT MANUFACTURING VS. FUSED DEPOSITION MODELING - MACHINE COMPARISON

PILIPOVIC, A[na]; SERCER, M[laden]; STOJANOVIC, I[van]; BRAJLIH, T[omaz]; DRSTVENSEK, I[gor] & VALENTAN, B[ogdan]

Abstract: *Products made by additive manufacturing are increasingly replacing the products made by classical procedures of polymer processing. The current market requires the products to be of good mechanical properties, low prices, and complicated geometry. With the procedures such as Fused Deposition Modelling and Laminated Object Manufacturing it is possible to produce a product of relatively low price and good mechanical properties. In practice it is impossible to avoid using the products in various atmospheric conditions (e.g. UV radiation and humid environment) either intentionally or unintentionally. The UV light, the Sun being its usual source,, and the average humidity of countries worldwide can vary from 20% to 90%, depending on the weather, day and geographic location. It is therefore necessary to determine how UV light, after a longer exposure, affects the final mechanical properties of the products. A comparison of tensile strength and elasticity module of the test specimens in FDM and LOM procedures has been performed.*

Key words: *fused deposition modeling – FDM, laminated object manufacturing, LOM, tensile strength, modulus of elasticity, UV light*

1. INTRODUCTION

1.1. Fused deposition modelling (FDM)

Fused deposition modelling (FDM) is a rapid prototyping procedure which was originally developed at the *Advanced Ceramics Research (ACR)* Company in Tucson, Arizona, but was then significantly improved by the *Stratasys Company*. The procedure starts from 3D CAD model, which is sliced by computer software into horizontal layers. The filament (e.g. polymer or wax) is supplied to the machine through a nozzle, which is computer-controlled and in one layer it forms the raster of the item in the respective layer. The material exits the nozzle in liquefied state and at ambient temperature hardens quickly. The entire system is usually in a heated environment. After making the first layer, the working bed is lowered for the thickness of the new layer and the new layer is extruded (Liou, 2008, Gibson et al., 2010, Pahole et al., 2005). In more complex prototype geometry, the support structure may be used. In this case a double extrusion head is used. The thickness of the layer depends on the nozzle opening, material dosage and the rate of feeding the material and it usually ranges from 0.18 mm to 0.5 mm (Gibson et al., 2010, www.alexdenouden.nl). It is possible to extrude also biocompatible and/or biodegradable materials (e.g. polycaprolacton – PCL) and elastomers and it is possible to simultaneously produce several prototypes (Pahole et al., 2005, www.dimensionprinting.com). The mechanical properties depend on the position of the prototype on the working bed, especially in the direction of z-axis (Liou, 2008, Gibson et al., 2010; Godec, 2005).

1.2. Laminated Object Manufacturing - LOM

The LOM procedure is used to manufacture a prototype by lamination and laser finishing (cutting) of materials such as paper, polymeric films and foils, and metal laminates. With polymeric foils better mechanical properties are achieved than with paper. The sheets are laminated into solid blocks by adhesion-joining, clamping and ultrasonic welding. (Liou, 2008, Kunwoo, 1999, Gibson et al., 2010). After a layer (foil) has been deposited, the laser beam or knife cuts a part of the material into the form of the finished product. The Company *Solido* from Israel, in their laminated object manufacturing procedure use film on which a layer of glue is applied, which is then cut by a knife into adequate form. Then, an "anti-glue" layer is applied on certain places where there is no prototype, i.e. the glue is neutralized. The next film layer is applied and it is glued to the previous one and the prototype is manufactured all the way to the final layer. When the last layer is finished, the excess material is removed from the prototype manually (Liou, 2008, Kunwoo, 1999, Gibson et al., 2010, Godec, 2005). The LOM features small shrinkage, low residual stress and warpage, allows fast manufacturing of big parts, the machines do not use toxic materials so that no special area is needed, and the prices of equipment and materials are low in comparison with other RP procedures (Liou, 2008, Gibson et al., 2010, Cooper, 2001). The mechanical and thermal properties are non-homogeneous due to the use of glue between the layers, and during removal of unused material small parts can be damaged, so that it is not possible to manufacture hollow parts (Gibson et al., 2010, Pahole et al., 2005, Lim, 2002).

2. COMPARISON OF MACHINES FOR FDM AND LOM PROCEDURE

The *Stratasys* cheapest model of the device is *Dimensional uPrint* from the *uPrint* family, the price of which is € 12000 upward. The device is based on the principle of FDM procedure and can make parts of *ABSplusTM* material, but only in one colour (Ivory). The characteristics of the uPrint device are: build size: 203 x 152 x 152 mm, layer thickness: 0.254 mm, machine size: 635 x 660 x 800 mm, machine mass: 76 kg. (www.dimensionprinting.com).

The test specimens made by LOM procedure are made of PVC film. The test bodies in LOM procedures are made on the *SD 300 Pro* machine, produced by *Solido*, is a machine which can produce transparent prototypes of PVC film, has small dimensions, and is practical for use in offices. The price of the basic model *Solido SD 300 Pro* with the basic set of materials is approximately € 11000. The characteristics of the *SD 300 Pro* machine are: precision: 0.1 mm (in axis), layer thickness: 0.168 mm, working area: 160 × 210 × 135 mm, machine size: 465 × 770 × 420 mm, machine mass: 45 kg (www.solido3d.com).

The printers have similar working volumes and price, which makes them favourable for small companies. They belong to the class of personal printers, which means that in service there is no health-harmful impact on the environment, and the installation is simple. The characteristic of both machines is the making of products of smaller dimensions with recyclable material.

3. EXPERIMENTAL PART

To determine the mechanical properties, the tension tester "Messphysik Beta 50 - 5" was used. The control unit was EDC 100, of maximal load force of 50 kN. To determine the extension properties the test specimen was fixed by the tester jaws and extended with force *F*, at speed *v* = 5 mm/min, as defined by ISO 527:1993 standard.

The test specimens were produced in the working space of the machine in the xy plane, of maximum height of 4 mm. The test included the tensile stress and the module of elasticity of the test specimens made by FDM and LOM procedure after natural exposure to UV light after 120 days and laboratory exposure to UV light after 42 days. According to ASTM D3-424 standard, 1 hour of laboratory testing in the UV chamber corresponds to 24 hours of natural exposure to UV light in Europe. Then, the comparison was made with the test specimens that had not been exposed to the light sources. The UV chamber model was *SOLARBOX 1500e*, manufactured by *ERICHSEN*.

In the FDM procedure the acrylonitrile/butadiene/styrene (ABS) material was used in the form of a wire, and in the LOM procedure poly(vinyl-chloride) (PVC) sheet was used.

The comparison of the procedures (Fig. 1) shows that the tensile strength in the test specimens made by the LOM procedure is better. Also, after exposure to light, the adhesive between the layers was additionally reinforced, thus increasing the tensile strength. In the FDM procedure the strength is decreased, and it is half the amount of the strength of test specimens made by the LOM procedure.

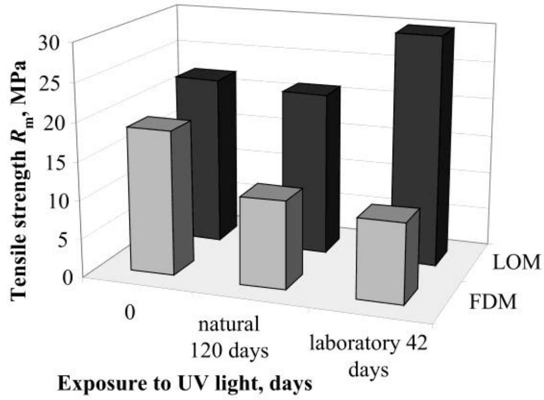

Fig. 1. Comparison of tensile strength in FDM and LOM procedures after exposure to UV light sources

From the diagram in Fig. 2 the module of elasticity may be noted which in the LOM procedure, after laboratory exposure to light increases, while with natural ageing the module inexplicably decreases.

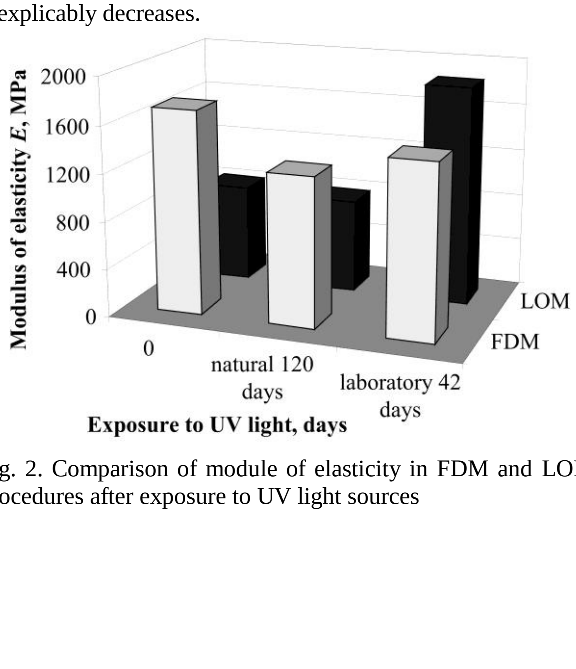

Fig. 2. Comparison of module of elasticity in FDM and LOM procedures after exposure to UV light sources

4. CONCLUSION

The limitation of this paper is in performing the comparison using only one machine in each process and one type of material. However, the choice is limited to the most popular pair of machines for FDM and LOM processes and to the commonly used polymers.

Both printers have acceptable prices and give products of good properties. In the LOM procedure, i.e. *Solido*, one should take into consideration the reduction of mechanical properties in z direction and the problems of removing the support material, which is sometimes impossible to remove. Before the production itself, the geometrical complexity of the product has to be analysed and the decision made about its orientation and position, as well as of the direction of peeling cuts. In the LOM procedure, one of the negative characteristics is the impossibility of recycling of the PVC sheets with the additions of adhesive between the layers.

The FDM procedure in the test machine is limited by the choice of the material and the roughness important for the FDM technology. The removal of the supporting material has been solved by simple dissolution in water solution, but this system raises the price of the machine itself.

By comparing the carried out tests it may be concluded that the tensile properties are significantly lower than in products made by classical procedure of polymer processing. However, today's market requires output of products in the shortest time possible, which gives additive technologies additional advantage. The exposure to various atmospheric influences (UV radiation) results in the reduction of the properties in the FDM procedure, whereas in the LOM procedure these properties are improved, which is the reason for the solidification of the adhesive layer between the laminates.

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