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Waste paper molding using 3D printed tools

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Introduction

Packaging creates significant impacts on the environment at all stages of its life cycle, however, these cannot be isolated from the impact of the product it protects. The life cycle of packaging represents a series of interrelated stages through which packaging as a product goes, from obtaining raw materials to its final disposal as waste. It begins with the production of packaging materials and packaging, continues its life cycle with packaging and storage of products, and ends as discarded packaging (Lazić & Novaković, 2010). Although packaging is crucial for the preservation of packaged products, used and discarded packaging can represent a significant environmental problem. Inadequate disposal of polymer packaging and other polymer products causes many harmful defects, leading to more and more plastic being found in natural aquatic and terrestrial ecosystems (Gvoka et al., 2022). The study found that more than 4.8 million metric tons of plastic waste enter the oceans from land each year, and that figure may be as high as 12.7 million metric tons (Cohen, 2015). The solution to this problem certainly lies in replacing polymer packaging, primarily polymer wrapping materials, with paper-based packaging whenever possible. Paper is a widely available material that can be recycled up to four times without significantly losing its characteristics. Today, packaging based on cellulose fibers plays a significant role in the storage and transportation of goods. This packaging is most often made from waste paper material, such as newspapers, used cardboard, and so on. These materials give new life to paper waste and reduce the amount of virgin paper used in packaging to an acceptable minimum.

Methods

In order to perform the experiment, it was necessary to define the geometry of the tool for forming process. The tool has consisted of two separate mold halves. The overall dimensions of both halves are 50x50 mm, with a draft angle of 2°. One of the influential factors that needed to be tested was the variable depth, therefore tool pairs were modeled for indentation depths of 1 mm, 3 mm, 5 mm, and 7 mm. These CAD models were created using 3D software Autodesk Inventor Professional 2022, and then converted to an STL document, suitable for further processing in the software Ultimaker Cura 4.11.0. The tool models were printed in the laboratory at the Department of Graphic Engineering and Design, at the Faculty of Technical Sciences in Novi Sad, with an FDM 3D printer Creality 3D CR-10s Pro V2. Each model is printed individually with the addition of the initial layers of the substrate, centered on the platform, to avoid possible printing errors, which has proven to be good practice on this device. Material PET-G 3031 was used for printing, due to its hardness, flexibility, and moisture and gas resistance. For the realization of the experiment, it was necessary to prepare two types of samples: (1) paper pulp based samples and (2) samples from waste paper materials in stacks. White offset paper with a weight of 80 g/m^2, collected as waste paper material in the laboratory of the Department of Graphic Engineering and Design, was used as the basic material for the production of paper pulp, which was previously cut into pieces whose dimensions are 20x10 mm. The materials that were used in the experiment to create samples represent the most common examples of paper packaging waste and they are: offset paper, natron paper, newspaper, tissue paper, corrugated cardboard (three-layer) and solid gray cardboard.

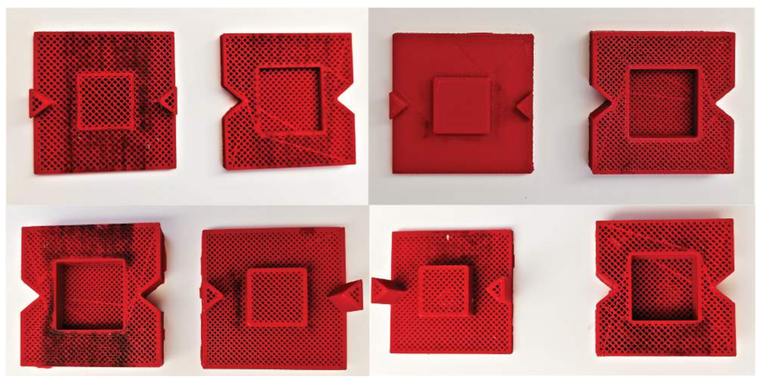

Figure 1
Models of tools printed with FDM 3D printing technology

The experiment of pressing the samples and forming the desired shape was performed at the Department of Graphic Engineering and Design, using a Shimadzu Compact Tabletop Testing EZ-LX device, with a measuring cell intended for forces of 2500 N, with a speed of movement of the pressure head of 100 mm/s, at a temperature of 25 ± 2°C. The experiment procedure involved positioning and fixing the tool for forming the shape of the samples on the compressive strength test plates, by taping one half to the lower plate and the other to the upper plate, and then placing the sample on the surface of the mold half. Using Trapezium X software, the device is programmed to apply a pressure force of 2000 N to the sample for each test, in Compression mode, for a duration of 30 seconds.When the scheduled time expires, the upper pressure plate is lifted manually, by entering the value on the control panel, the formed sample is taken out of the lower half, taken to dry and a new sample is placed in its place for subsequent testing. Testing was performed five times for each material.

Results

The criteria for evaluating samples are the uniform depth of the sample, the clarity of the edges, the reproduced geometry, and material damage. A comparison of samples made from different waste paper materials made with a tool for forming a depth of 7 mm was performed, then a comparison of samples made from the same material for depths from 1mm to 7 mm was made. It was confirmed that samples made of offset paper and tissue paper are the most uniform in terms of geometry formation, edge reproduction and degree of material damage, while significant damage was observed on samples made of newspaper and solid cardboard. In the case of samples made of natron paper, one can see the vagueness of the edges. After comparing paper pulp samples, it was determined by the method of visual quality assessment that the samples made from the offset paper stack proved to be a better choice compared to the paper pulp samples, in terms of the shaping of the material under the influence of pressure force.

Figure 2
Results of forming samples from offset paper and tissue paper

Conclusion

In addition to the obligation that the packaging must fulfill towards the potential customer, it also has an obligation towards health and preservation of the environment. With the increase in the volume of serial production, there is an increasing amount of packaging waste, which, due to improper handling and inadequate disposal, increasingly becomes a polluter of aquatic and terrestrial ecosystems. This is precisely why it is necessary to consider the use of healthy, alternative, environmentally sustainable materials for the production of graphic packaging. Based on the performed experiment, it is possible to conclude that the samples made of waste paper materials, primarily offset paper and corrugated cardboard, proved to be satisfactory in terms of forming and reproduction of geometry. In the majority of samples made of waste paper material, damage to the material can be seen, especially on the samples made with a 7 mm depth tool, while the samples made with a 5 mm depth tool proved to be the optimal solution. After comparing samples, it was determined by the method of visual quality assessment that the samples made from the offset paper stack proved to be a better choice compared to the paper pulp samples, in terms of the shaping of the material under the influence of pressure force.

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