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SIMULATIONS OF COSMETIC PRODUCTS MADE FROM BIODEGRADABLE MATERIAL

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Abstract: The environment pollution caused by polymer wastes is becoming more problematic. Dozens million kilogram polymers are thrown away every year, and they pollute not only the waters but the whole world. One of the solutions for this problem is the usage of biodegradable materials. With the application of biopolymers, the pollution of the environment can be reduced. This paper deals with the designing and simulations of environmentally friendly products. The injection molding simulation of a lipstick and a razor is introduced. Furthermore, the load capacity of the razor was examined by applying finite element simulations.

Keywords: *Biopolymer, injection molding, simulation, FEM, polymer pollution*

1. INTRODUCTION

We took part in an international multidisciplinary co-operation among JAMK University of Applied Sciences Jyväskylä, Universidad de Jaen and University of Miskolc. This project was a part of EU funded HEIBUS project that aimed to develop smart and innovative new methods including virtual implementation. In this project eighteen students were divided into three groups, two people from each country (Hungary, Finland and Spain). During the whole project, students had support of supervisors to solve real life problems using eco-friendly materials. All three groups worked independently on the same topic. The topic of the project was: *Reducing the environmental footprint through the development of new and biodegradable plastic products*.

This theme was given by Andaltec, which is a non-profit-making technological centre located in Southern part of Spain, Martos. The topic aimed at designing and developing sustainable, eco-friendly products, as alternative to disposable polymeric products that has great impact to nature. The group needed to decide the product to be developed thoroughly by using systematic tools and research methods. It was expected from teams to produce clear identification of the product and improved functionality using biodegradable polymeric alternatives. Material to be used was already limited to four 100% bio-based and biodegradable materials: PLA, PHA, TPS and Cellulose acetate. During the design CAD, FEM and CAM tools were needed to analyse, simulate and present the products. A final prototype was developed and manufactured using current plastic technologies such as FDM 3D Printing.

In the following sections we are going to introduce our part of the project work. First the 3D models of the chosen products were created, afterward injection molding simulations were used to determine the properties of the injection molded products. Finally, finite element simulations were made to define the appropriateness of the product.

2. POLYMER POLLUTION IN THE WORLD

Each year around 300 million tons of plastic are produced around the world. 50% of this is disposable product. 4.6% of the annual petroleum utilization in the U.S is used up by the plastics manufactures. The energy which is consumed this way cannot be recovered. 34 million tons of plastic was disposed in the United States in 2008. 86% of this ended up in landfills [1].

Among the four islands of the Pitcairn Archipelago, the largest is the Henderson Island, which is on the UNESCO World Heritage List and one of the few parts of the world. The ecology of this island is virtually untouched by humankind. There are a number of unique biological attractions on the island, considering that it is only 3700 hectares, with 10 endemic plants and 4 bird species. The isolation of the island has protected this area from human activity until today. However, this island is packed with 18 tonnes of waste, which has the highest density of anthropogenic debris in the world. 99.8% of the waste is made up of plastics, which means 38 million plastic products. Most of the waste (about 68%) is not visible, as nearly 4,500 items per square meter are hidden up to 10 cm deep. Approximately 13,000 new wastes drift to the shore on a daily basis. Hundreds of crabs make their homes out of plastic debris, such as cosmetic tubes or bottle caps *(Figure 1)*. Thus, one of the most desolate islands is also the most polluted part of the world [2].

Figure 1. Henderson Island [2]

Examples show that the usage of the polymer materials causes huge damage in the environment. Therefore, new solutions are needed to reduce the ecological footprint. One possibility to solve this problem is the development of biopolymer products.

2.1. Biopolymers

Biopolymers are typically natural-based, renewable resources produced by polymers if they are placed in a biotic environment or soil-composite due to the enzymatic breakdown of bacteria, fungi or algae they break down to invisible particles without contaminating the environment. This can take a few month, perhaps a few year [3].

Figure 2 illustrates the categorization of polymers based on the biodegradability of the material and the basic composition. The three main material types are the oil-based, partially bio-based and 100% bio-based polymers. Those materials were chosen that are bio-based polymers and in the same time they are also biodegradable. This group contains the PLA, PHA, TPS and cellulose acetate.

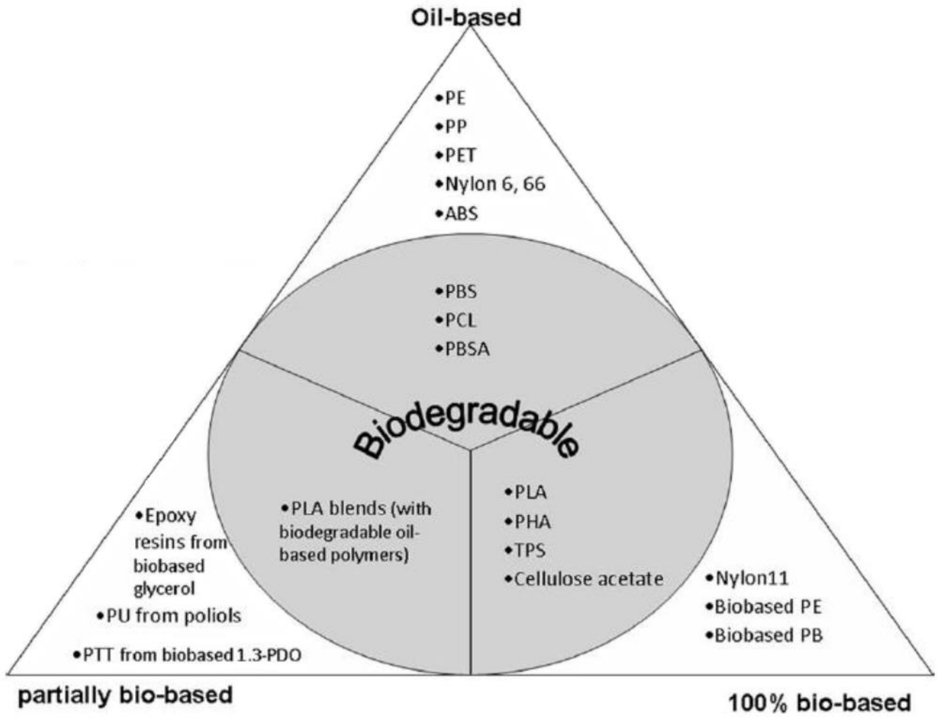

Figure 2. Categories of polymers based on the main material and biodegradability [4]

The chosen material of the products was the PLA. It is made from starch or sugar extracted from biological materials such as wheat, corn and sugar beet. As a first step, the starch or sugar is broken down into glucose by acidic hydrolysis. When fermented, lactic acid is formed from glucose in the presence of lactic acid bacteria. The PLA has good mechanical properties, its shrinkage is low, but it is brittle and the impact strength of it is small. It has a low heat resistance (55–65 °C), it is hydrophilic but not water-soluble, the resistance of it against grease and aroma is excellent. Furthermore, it is resistant to UV light and alcohols, but not to acids and alkalis.

The PLA can be processed with conventional polymer processing technologies (for example: injection moulding, vacuum forming). The degradation of it produces water, humus and carbon-dioxide, thus it does not pollute the environment. It is compostable and the process goes through in a few months, it is not degradable in biotic environment [3], [5].

3. 3D MODELLING OF PRODUCTS

Product ideas were gathered by brainstorming sessions. After narrowing the view using different tools we chose the lipstick and the disposable razor. We wanted to make the design to look like an organic plant to draw attention for the fact that the product is eco-friendly. A bamboo theme was chosen as final concept. They work as a reminder of our environmental stage and offer good stand for effective design in all the simplicity. In the following the geometry of the two products is shown.

3.1. The razor

The geometry of the razor was made with Creo Parametric 2.0 Software. We focused on the design of the handle part instead of the blade, because the blade should be metal, and the handle can be eco-friendly polymer. One of the main principles in designing was to provide shapes that support injection moulding. To use less material in the making of the razor we lighted it. The first version of the lightened razor can be seen on *Figure 3*.

Figure 3. First version of the razor

The result of the different kind of finite element simulations showed that the handle had a lot of unnecessary material, therefore with a new geometry the razor was lighted further. The final geometry is shown in *Figure 4*.

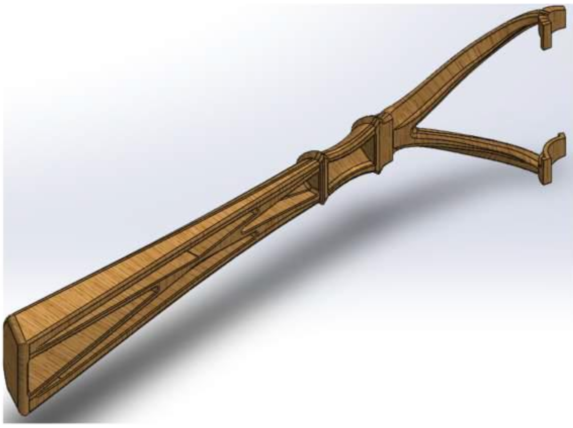

Figure 4. Final version of the razor

3.2. The lipstick

The lipstick has a simple mechanism which is of the rising system of the substance. The mechanism was impossible to do with a single part, so assembly was demanded. In case of the inner components the goal was to achieve a good functionality. The outer part needed to offer good grip and look like a bamboo. The geometry of the lipstick was made in SolidEdge ST5 software and the appearance and the sectional view can be seen on *Figure 5*.

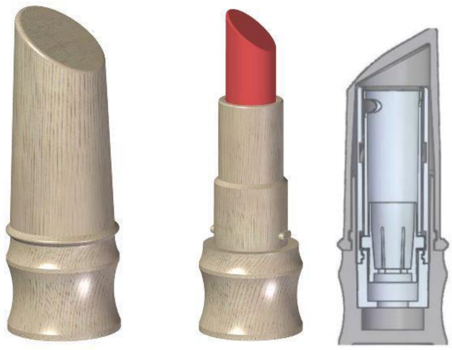

Figure 5. Geometry of the lipstick

4. INJECTION MOULDING

Injection moulding is the easiest method to produce a polymer product. Using injection moulding the products can be produced relatively fast and in large quantities even with complicated geometries. The system can be automatized; however the equipment and tools require high investments with a large amount of processing waste. During injection moulding the plastic is melted then it is pressed into the closed cavity, which shapes the product. After the plastic is solidified, the tool is opened, and the finished product is removed. In a full injection moulding simulation, there are four main sections: filling, packing, cooling and warpage. In the filling section the melt is filled in the form on a given temperature. From this information about the filling time, the melt front temperature, the air drops (little air bubbles inside the product) and the welding lines are gotten. In the cooling part the ejection time is shown.

4.1. Process of the injection moulding simulation

The process of the injection moulding simulation is presented through the simulation of the razor. The same steps were performed in case of the lipstick parts too.

The Moldex3D software divides the injection moulding simulation in two parts. The first module involves the geometry and mesh generation of the cavity, runner and cooling systems, definition of the material and creation of the simulation files, while in the second module – the process parameters setting and the results of the simulation. The first module is the Moldex3D Designer. It consists of two solution modes, the eDesign and the Boundary Layer Method (BLM). The first solution generates the 3D mesh automatically, but in case of the BLM mode the user sets the parameters of the mesh and the program makes the mesh denser near the surfaces as the most important changes accrue here during the injection moulding.

At the next stage, the location of the gate has to be selected. The gate is a designed small opening where the melted polymer is injected into the mould cavity; a successful gate design is determined by the gate type, the dimensions and the location. The position of the gate is influenced by the thickness of the geometry: the gate has to be at the thicker part in order to have steady filling.

With the position of the gate the length/thickness ratio can be checked. If this value exceeds 200, then the injection moulding of the product cause difficulties more gates are recommended to be used. The calculation method of this ratio can be seen in *Figure 6*.

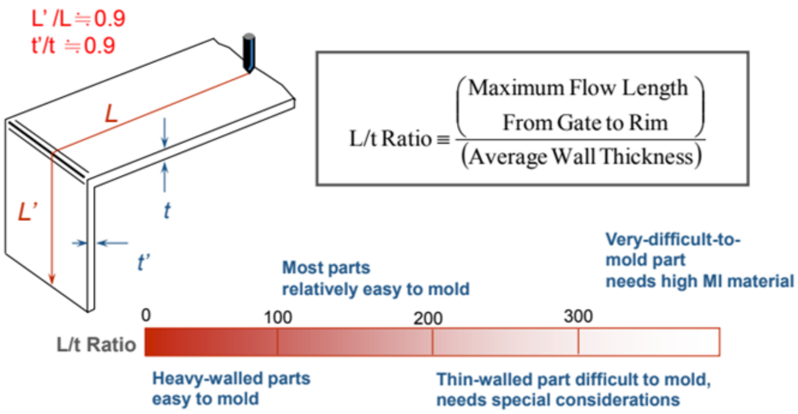

Figure 6. Calculation of the flow length and the wall thickness ratio [6]

The next task is the sizing of the mould base. The exact values of this component were not known, thus the default dimensions provided by the program were used. One of the steps in establishing the settings of the simulation is the design of the cooling system. In this case a simplified version was made to make the calculation time short. The layout of the cooling system can be seen in *Figure 7*.

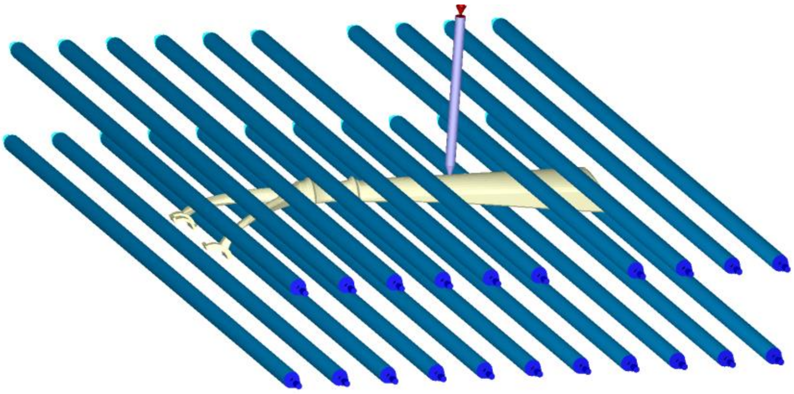

Figure 7. Layout of the cooling system

The final step involves the mesh setting. The previously described BLM method was selected, and three layers were defined near the surface. Application of too many layers in the skin increases the number of elements in the mesh, and the computational time would be extended too. A section of the completed mesh is illustrated in *Figure 8*. Enlarged view shows well that near the surface and around the gate the mesh is denser. This way the calculation will be more accurate.

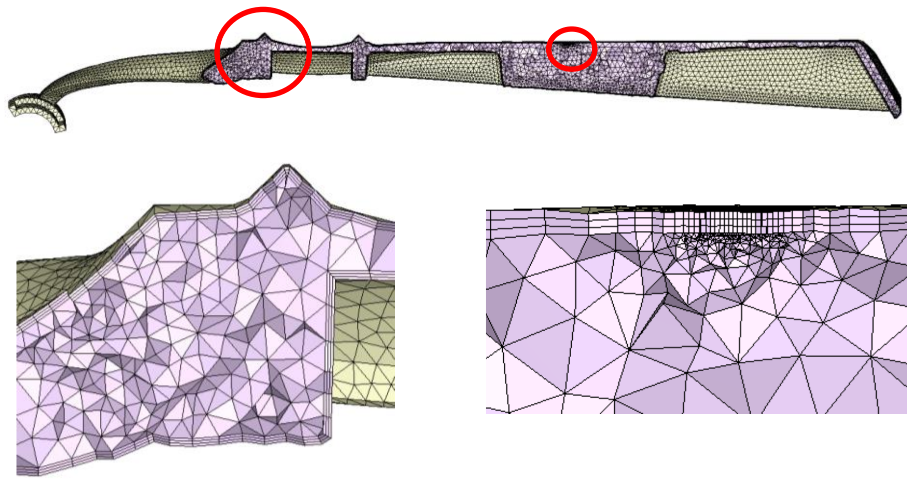

Figure 8. Meshed geometry

The additional parameters have to be adjusted in the second module of the program. It includes for example the setting of the melting temperature, the packing pressure, the cooling temperature.

The chosen material was the Ingeo 3251D PLA made by Nature Works. A few properties of it are shown in *Table 1*.

Table 1.
Properties of the material

Properties	**Value**
Young modulus [MPa]	3.5
Poisson ratio	0.36
Relative viscosity	2.5
Tensile strength [MPa]	62

The complete injection moulding simulation was performed, in particular the process of filling, packing, cooling, and warping.

4.2. Results of the simulations

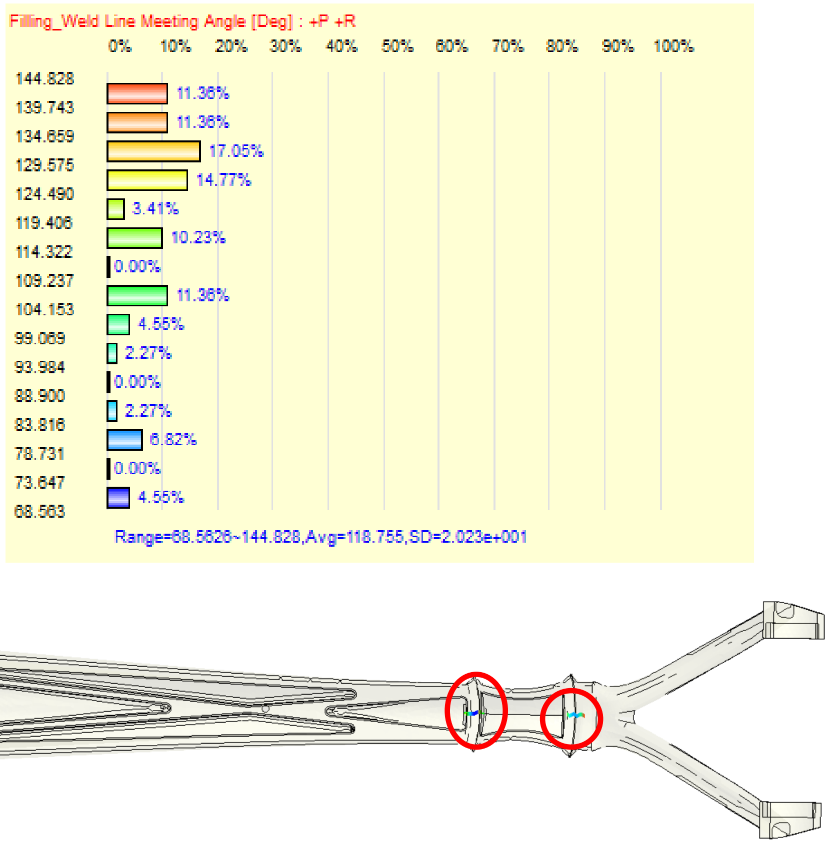

Figure 9. Position and meeting angle of the welding lines

Mainly the magnitude of warpage and the position of the weld lines were examined. Weld lines accrues when two melt fronts meet. These lines can cause huge deterioration in the mechanical properties of the product. This problem occurs when the angle between the melt fronts is smaller than 45°, otherwise the reduction is insignificant. The results about the welding lines are illustrated in *Figure 9*. It shows that the minimal value of the meeting angles is around 68° which is higher than the minimum limit value, thus the welding lines do not cause significant decrease in the mechanical properties.

One of the most important results of the injection moulding simulation is the warpage. The process of warpage is affected by the geometry (variation of the thickness or the direction of the flow), the process (variation of the melt temperature, mould temperature or the packing time), the shape (redesigning of the cooling channel or the gate) and the material. The result is presented in *Figure 10*. The maximal value of the warpage is around 1 mm and it occurs at the end of the razor. This displacement is too large because this connecting part has to be as accurate as possible. Further simulations are needed.

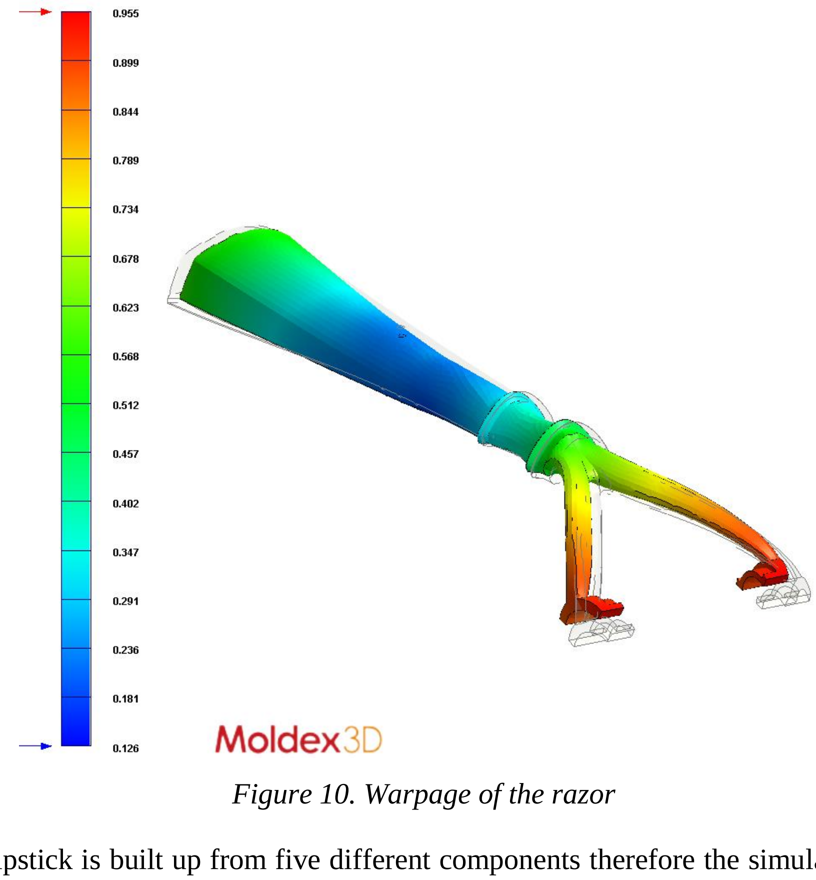

Figure 10. Warpage of the razor

The lipstick is built up from five different components therefore the simulation for every part was made. The main steps were the same as described with the razor. The meshed parts can be seen in the figure below. Several simulations were made however in the paper only the final results are shown.

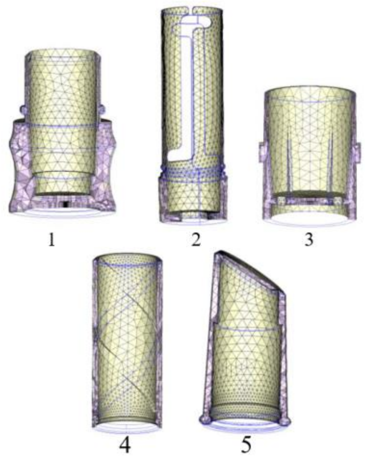

Figure 11. Meshed components

A few results are collected in *Table 2*. The L/t ratio of every component was well below the acceptable value, which is 200, thus only one gate was used to make the injection moulding of the parts.

Table 2.
Results of the different part of the Lipstick

	Part 1	**Part 2**	**Part 3**	**Part 4**	**Part 5**
L/T ratio	35.7	80.3	38.7	43.8	60.6
Filling time [s]	0.193	0,101	1.509	0.101	0.139
Cooling time [s]	34.813	6.366	6.366	6.06	12.942
Angle of the welding lines	–	143.908°	89.045°	144.141°	32.891°
Maximal warpage [mm]	0.201	0.128	0.0494	0.0942	0.367

The cooling time of the part 1 was reduced to the half of the previous simulations, however this value is still too large, therefore further changes have to be made. The solution can be the changing of the geometry or the cooling system. The angle of the welding lines only in case of the fifth part is problematic. As it was mentioned earlier the welding lines can cause huge deterioration in the mechanical properties of the product if the angle is lower than 45°. This problem can be solved with the changing of the geometry. Another solution can be the usage of more gates, because the direction of the flow will change.

The warpage of every component is lower than 1 mm. Received values are sufficient and modification is not needed. *Figure 12* illustrates the distribution of the warpage in case of the five components.

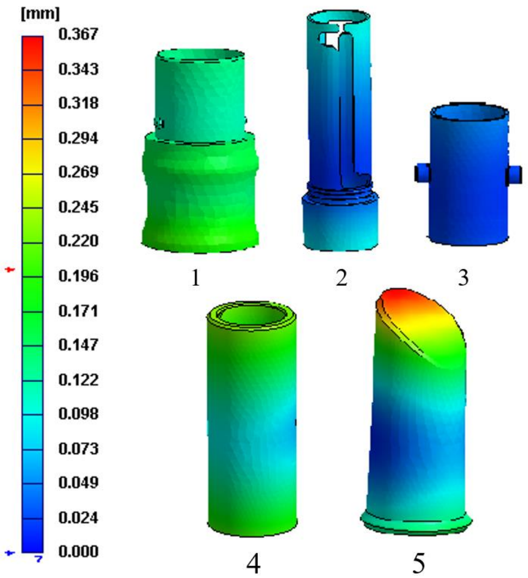

Figure 12. Warpage of the lipstick components

5. Finite element simulation

The finite element simulation was performed using Marc software to check the load capacity of the razor. The simulation of many physical problems requires the ability to model a contact problem. This includes representing the friction between surfaces and heat transfer between bodies. In case of the razor only the forces and the friction between surfaces was taken into account. There are two types of contact bodies in Marc, deformable and rigid. In a contact analysis, a distinction is made between touching and glue conditions. In a structural analysis, a touching condition still allows relative sliding of the bodies in the contact interface. A glue condition suppresses all relative motions between bodies.

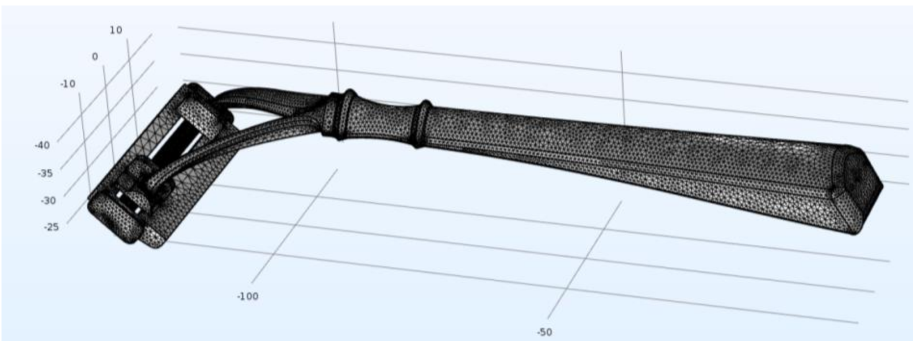

Figure 13. Generated mesh in Comsol Multiphysics

COMSOL Multiphysics program was used to make the mesh of the razor (see *Figure 13*), because the Marc Mentat built-in automatic meshing function was inaccurate. The following picture shows the different parts of the razor which include the blades, the head and the handle. The smaller parts were not taken into account during the finite element simulation.

Figure 14. Parts of the razor

After importing the mesh into the Marc Mentat the connections between the components were made. The blades of the razor were glued in the head therefore their movements were not permitted. Between the head and the handle touching was assumed just like in case of the head and the rigid surface. The following step was the setting of the boundary conditions. Usually the users hold the razor around the "neck" of the handle, thus the degrees of freedom of these nodes were tied. This and the placement of the rigid surface are shown in *Figure 15*.

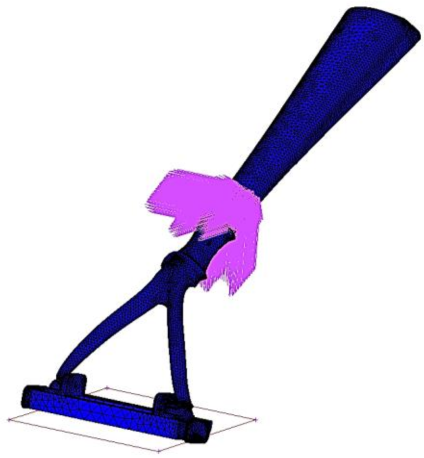

Figure 15. Placement of the surface and the fixed boundary condition

Two simulation cases were examined. In the first case the initial moment of the movements was simulated. It includes the moving of the razor and supervening of the contact between the razor and the surface, therefore the rotation of the head was not permitted. The load was put on the structure in more steps. The maximal von Mises equivalent stress was 8.34 MPa. This value is below the tensile strength of the material thus the razor can withstand this stress. Therefore, this maximal stress occurred around a stress concentration place, thus with the refining of the mesh this value would be lower. The distribution of the equivalent von Mises stress is shown on *Figure 15*.

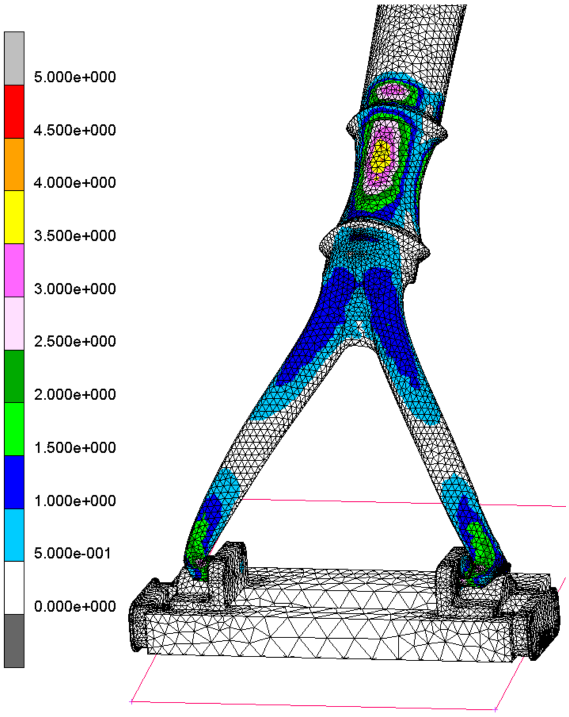

Figure 16. Distribution of the equivalent von Mises stress in case of the first geometry (first simulation)

In the second simulation besides the vertical loading the surface was rotated with 5°. In the first second of the simulation the load was put on the structure after reaching the given value the load stayed constant. In the first second the surface was not allowed to rotate, the rotation started in the second part of the simulation where the load was already constant. In this case the maximal equivalent von Mises stress was 10.81 MPa. This is also well below the acceptable value. This was one of the reasons that the lightening of the razor was taken into consideration, and finally it was changed to the new geometry, which is shown on *Figure 4*.

The same finite element simulations were made in case of the final geometry too. The process of the setting was identical therefore these steps are not introduced again. The maximal equivalent von Mises stress was 12 MPa. The razor can withstand this stress. It occurred at the “neck” part of the handle, which is circled on Figure 16. This part of the razor is a stress concentration place therefore with the refining of the location this value would be lower.

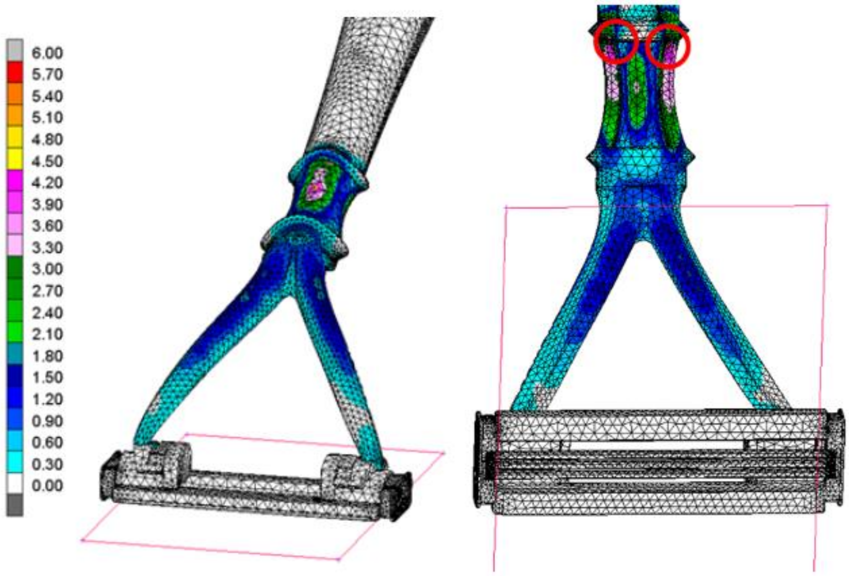

Figure 17. Distribution of the equivalent von Mises stress in case of the final geometry (second simulation)

6. Summary

The above introduced products and the simulation of them proves that the razor and the part of the lipstick can be made from biopolymer. It can help reducing the ecological footprint. The following numbers prove this.

According to a survey, the American lipstick users were estimated to be around 135.99 million people. This data is from 2011 [7]. The weight of a lipstick is approximately 36.12 gram. Therefore, if every second American user would buy lipstick made from bio-friendly material then the polymer waste would be reduced by 2.4 million kilograms every year. The weight of the razor is around 9.6 gram, and the usage is wider thus this value is higher in case of the razor.

7. Acknowledgement

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