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BOOSTING THE SCIENTIFIC EXCELLENCE AND INNOVATION CAPACITY OF 3D PRINTING METHODS IN PANDEMIC PERIOD

TOOLKIT 6

Rapid tooling

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Content

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1 Introduction.

Throughout history, artisans have used molds to make everything from Bronze Age weaponry to modern-day consumer products. While early molds were commonly shaped in stone, modern science has developed materials that are far easier to work with, such as silicone.

Today, a various industries rely on silicone molding. Product developers i.e., engineers, DIY makers, and even chefs all make silicone molds to create one-off or smaller runs of parts.

This practical guide referring to silicone mold-making will describe everything you need to know before getting started, provide a list of items you need, and give you a step-by-step guide for incorporating silicone molds into any type of project.

Silicone is a good choice for mold-making because it offers several benefits. You can easily create custom designs using silicone molding. The molds themselves are also quite durable, so you can use them repeatedly without the fear of breakage. Silicone's inorganic makeup—compared to rubber, its organic counterpart—makes it highly resilient to heat and cold, chemical exposure, and even fungi. Some of the benefits of silicone molds include the following ones:

Flexibility

Silicone's flexibility makes it easy to work with. Silicone molds are pliable and lightweight compared to stiffer substances like plastic and they are also easier to remove once a part is fully formed. Thanks to silicone's high level of flexibility, both the mold and the manufactured part are less likely to break. You can use custom silicone molds to shape everything from complex engineering components to holiday-themed ice cubes or confections.

Stability

Silicone withstands temperatures from -65° to 400° degrees Celsius. Additionally, it can have an elongation of 700%, depending on the formulation. Highly stable under a broad range of conditions, you can put silicone molds in the oven, freeze them, and stretch them during removal.

Durability

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In most cases, you will get many runs out of a silicone mold. However, it is important to note that the life span of molds can vary greatly. The more frequently you cast, and the more complex or detailed your design is, the faster your mold might degrade. To maximize the life of your silicone molds, clean them with mild soap and water, dry them thoroughly, and store them individually without stacking.

Common Applications for Silicone Molds

Hobbyists and professionals alike rely on silicone molds because of their versatility and ease of use. Here are a few examples of industries and applications that make silicone molds to produce prototypes, jewelry, food and beverage, consumer goods, medicine, etc.

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2 CAD model preparation for silicone molding

The purpose of this manual is to define and illustrate in detail the process of casting into a silicone mold. The joint of an orthosis reinforcement is used for exemplification. The joint consists of a pair of arms (parts R1 and R2) connected by a pin. These arms are currently made from metallic materials (Fig. 1). The purpose is to replace them with plastic ones so that they are lighter and more usable in healthcare.

Fig. 1 Real orthosis

In our case of orthosis arms, 3D CAD models of the components must be developed at first.

These models will be two, first part (R1) and the other part (R2). The NX software from Siemens is used for designing the 3D models.

The first step in creating a 3D CAD model is to select a suitable sketch plane. One of the three basic planes of the coordinate system, any planar surface of the existing body, or a newly defined plane can be used for sketching. A sketch of the base body is drawn in this plane (Fig. 2). This sketch needs to be fully constrained. The constraints can be geometric (concentricity, perpendicularity, parallelism, symmetry, etc.) or dimensional (linear or angular dimensions). Geometric constraints are always preferable, so that the number of dimensions is minimized.

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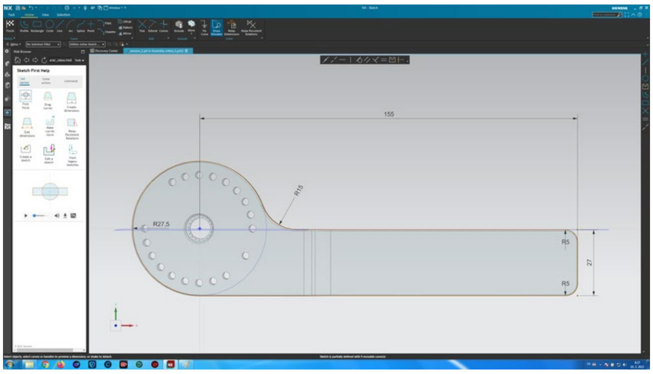

Fig. 2 Sketch of the part R1

Subsequently, various 3D operations can be applied to the sketch (rotation, extrusion, etc.) In our case, the extrusion is used to obtain the basic 3D part R1 (Fig. 3).

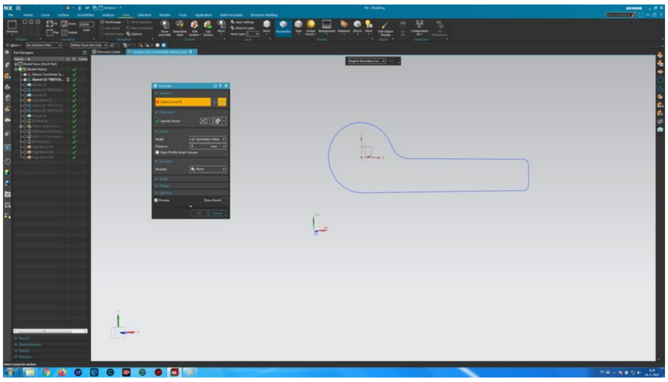

Fig. 3 Base body extrusion of part R1

Additional geometric elements will be created on this body. The appropriate sketch plane is selected again, the sketch is drawn and bound, then a suitable 3D operation is applied to the sketch (Fig. 4).

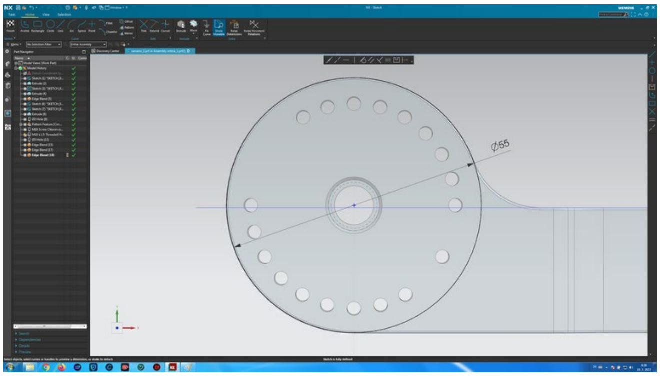

Fig. 4 Creating of another sketch

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Subsequently, the material is pulled out and a joint is created. It is necessary to create several identical holes, which will be distributed along a circle. A pair of such holes is created at first (Fig. 5).

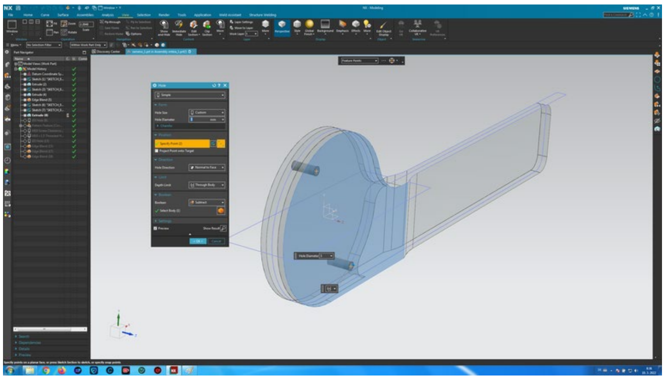

Fig. 5 Creating a pair of holes on the circle

Subsequently, using this pair of holes, an array of holes is generated as needed (Fig. 6).

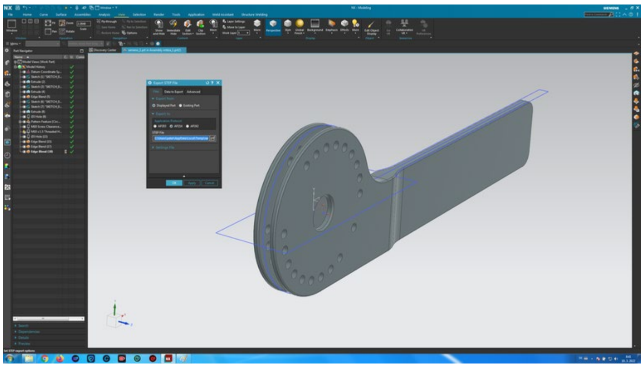

Fig. 6 Hole pattern generation

The next step consists in creating an axial hole for the joint (Fig. 7).

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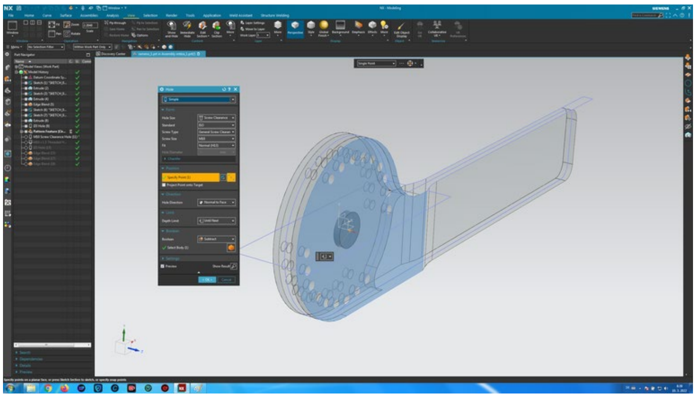

Fig. 7 Definition of the central hole

It is necessary to chamfer or fillet the resulting edges (Fig. 8).

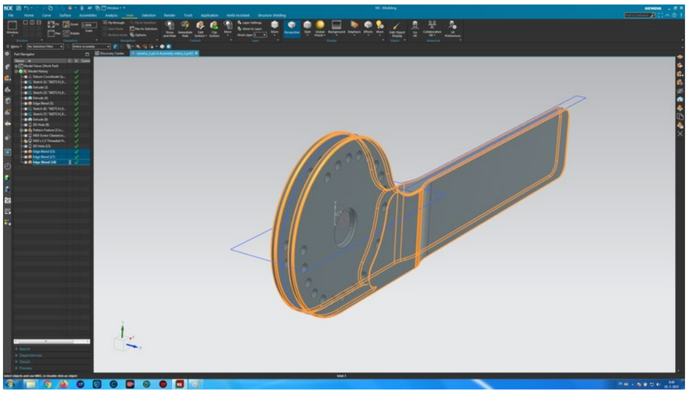

Fig. 8 Edge blending

This whole procedure is repeated until the required 3D CAD model is obtained (Fig. 9). The last operation is to export the 3D CAD model to STEP format for further processing.

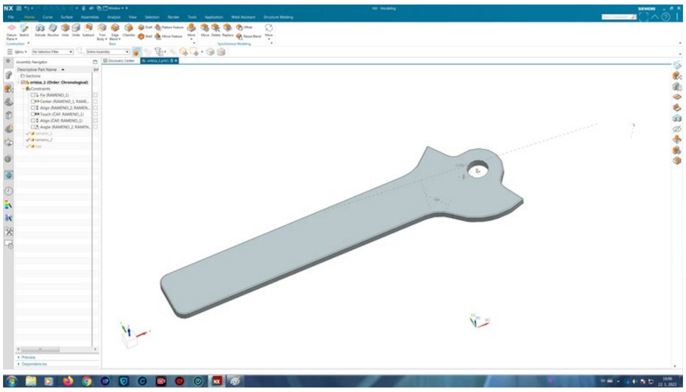

Fig. 9 3D model of part R1

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The 3D CAD model of the R2 arm will be generated in the same way. In the next stage, an assembly is created to verify the correct dimensions and shapes of the R1 and R2 arms. Figure 10 shows the assembly of the orthosis arms. The individual arms are connected in a joint using a pin.

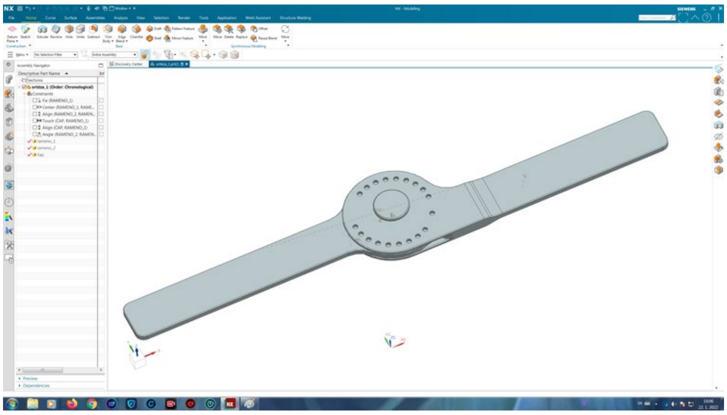

Fig. 10 Assembly of both parts R1 and R2

The 3D models of the individual arms are transformed into STEP files to be processed and printed on a 3D printer. The finished 3D arms serve as master physical models for producing silicone molds.

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3 Realization of casting into a silicone mold

MOLD PRODUCTION

The mold was produced for the parts R1 and R2, which were designed using the NX Siemens software and subsequently obtained by 3D printing (Fig. 11).

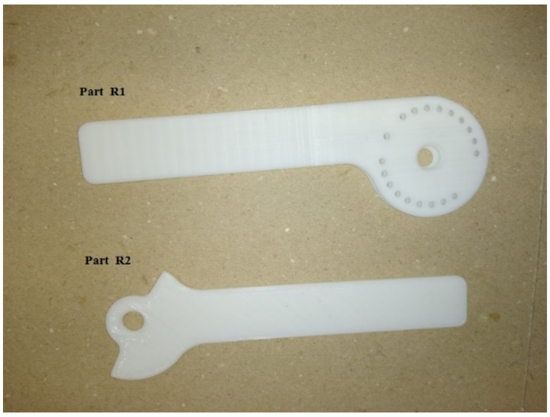

Fig. 11 Physical models of parts R1 and R2

The following aspects must be clarified before starting the production of the mold: appropriate production method, specific possibilities of fixing the mold, location of the separator to be used, and type of silicone to be used. Subsequently, the edges of the physical models R1 and R2 are cleaned, degreased, and trimmed. There is a notch on part R1 that needs casting. To ensure the shape of the notch, it is necessary to insert plexiglass, which also must be trimmed (Fig. 12).

Fig. 12 Insertion of plexiglass to the R1 model

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Double-sided tape is used to fix the R1 model onto plexiglass (Fig. 13).

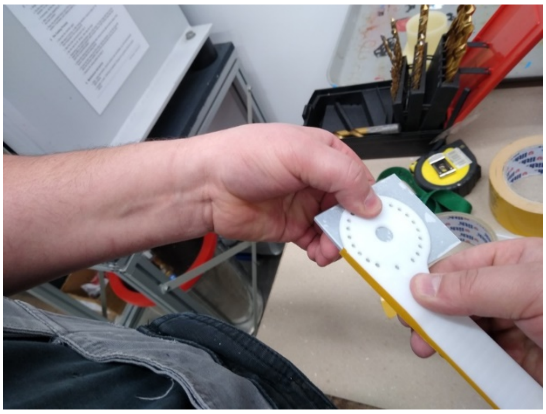

Fig. 13 Using double-sided tape to fix the R1 model onto the plexiglass

In order to achieve the shape of the part, the minimum wall thickness of the silicone mold must be 20 mm. Two cases are made of plexiglass plates. The dimensions of the cases are 10x22x10cm and 5x22x10cm, respectively. The individual parts of the cases are glued together (Fig. 14). In the company BIZZCOM it is advantageous to use plexiglass for producing the molds, because they use it as a waste material.

Fig. 14 Production of mold casing

The duct plane is used as a separation surface of the casting mold (Fig. 15). This strategy is used for both parts (R1 and R2).

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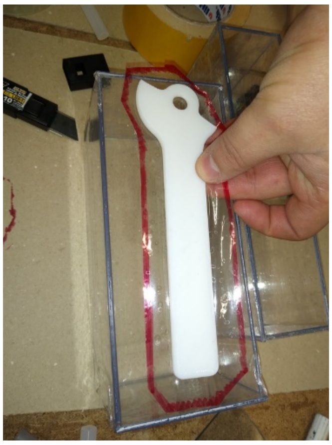

Fig. 15 Duct tape used for materializing the separation surface on the R2 model

The amount of silicone needed for producing the mold is determined in accordance with the exact dimensions of the cases. After re-evaluating the silicone preparation process, it is more advantageous to mix the entire silicone quantity at once than for individual parts. The silicone mixing vessel must be carefully cleaned. A mixing ratio of hardener and base component of 1:10 is recommended. The individual quantities of mixture quantities are as follows: 200 g of hardening agent and 2000 g of silicone. Before using it, the mixture must be freed of air bubbles and other gaseous impurities in a vacuum chamber for approximately 10 minutes (see Fig. 16 and Fig. 17).

Fig. 16 Weighing the hardening agent

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Fig. 17 Removing air bubbles and other gaseous impurities from the mixture of silicone and hardening agent in a vacuum chamber

The processing time of the silicone mixture is 60 minutes. This mixture of silicone has a long workability and low shrinkage (about 1%). So, it is possible to use it for producing accurate molds.

The silicone mixture is then poured into the case (Fig. 18). The aim is to determine a unique casting point and to pour the silicone slowly in the vicinity of the casing wall. The air bubbles remained in the silicone volume are simply removed by heating with a hot air gun or blowing warm air with a hair dryer.

Fig. 18 Pouring the silicone mixture into the case

The molds containing the physical models R1 and R2 are then allowed to harden (preferably for 24 hours). Unwanted air bubbles remained in the molds are removed in an MK-Mini vacuum chamber (Fig. 19).

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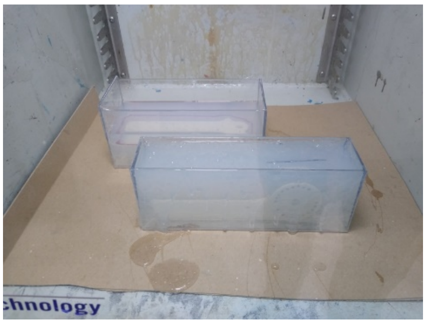

Fig. 19 Silicone molds for R1 and R2 parts placed in the vacuum chamber

REMOVING THE R1 PHYSICAL MODEL FROM THE MOLD

After the silicone has hardened, the mold must be removed from the casing and its edges must be trimmed. In the next stage, the embedded model must be also extracted. In order to do that, the silicone mold must be cut with a scalpel, but only so that the silicone can be open to remove the physical model (Fig. 20). The aim is to avoid the complete separation of the mold in two pieces (i.e., avoid any difficulties caused by joining and fitting the two parts of the mold). The plexiglass must be also extracted from the mold. R1 weight is the 25g.

Fig. 20 Removing the R1 physical model from the mold

Their mutual position is indicated on the mold and on the plexiglass with a marker (Fig. 21), to identify the exact position where the plexiglass is inserted into the mold before casting. Before inserting the plexiglass, its surface must be covered with a separator spray. The mold cavity must also be sprayed with the same substance. The separator will facilitate the separation of the casting from the silicone mold. The R1 physical model weighs 25 g.

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Fig. 21 Marking of mutual position

REMOVING THE R2 PHYSICAL MODEL FROM THE MOLD

While cutting the mold with a scalpel along the separation surface, the tip of the scalpel must be guided along the red line indicating the edge of the adhesive tape which will form the parting surface. In order to ensure the exact position of the two parts of the mold during the casting process, several protrusions must be made on the parting surface of the silicone mold. These protrusions will serve as a lock when assembling the mold. The R2 physical model weighs 10 g.

Five vent holes are created in the molds. These vents will allow the air to escape when the resin is poured into the mold (Fig. 22).

Fig. 22 Creation of five vent holes in the mold

CASTING INTO THE SILICONE MOLD

The plexiglass must be inserted before casting in the position individualized with the marker. As already mentioned, the surface of the plexiglass must be sprayed with a separator before the insertion into the mold (Fig. 23). The mold cavity must be also sprayed. The separator will

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facilitate the separation of the casting from the silicone mold. In our case, the mold cavity does not need to be sprayed with a separator because the resin used has no affinity, compatibility with the silicone mold material. In the case of epoxy casting, it is necessary to use a separator.

Fig. 23 Application of separator on the plexiglass

The mixing ratio is 100:45 (45 Polyol and 100 Isocyanate), the silicone form is heated to 70°C. The processing time is 8 minutes (after this time the resin is hardened). The time of mixing the components is 1 min -1.5 min. The mixing process takes place in a vacuum chamber at a pressure of -0.1 MPa. After mixing, the compound is poured into a nylon mold which is prepared in a vacuum chamber. After pouring the compound, the mold degassed for about 1 minute. After its removal from the vacuum chamber, the mold with the casting is placed in a heated oven for 90 minutes at a temperature of 70°C.

CASTING

Prior to casting, the plexiglass must be inserted into the silicone mold in the position indicated with the marker. Then the resin is prepared for the weight of part R1 (25 g).

In the case of part R2, about 20% of resin must be added for the inlet. This allowance is calculated to compensate the loss on the walls of the vessel, the loss on the stirrer and the like. A funnel is inserted in the mold placed in the vacuum chamber to be used for pouring the resin.

CASTING INTO THE SILICONE MOLD (1)

While mixing, a few drops of red dye should be added to the resin to better see the flow of the

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resin in the mold during casting (Fig. 24).

Fig. 24 Red dye added to the resin

After casting, the resin is hardened in the furnace. The casting is then removed from the mold. At first, the adhesive tape that holds the mold together is removed (Fig. 25).

Fig. 25 Removing the adhesive tape

This tape is cut with a trimmer. In our case, the product cracked when the part R1 was removed from the mold during the break-off of the inlet (Figs 26, 27 and 28).

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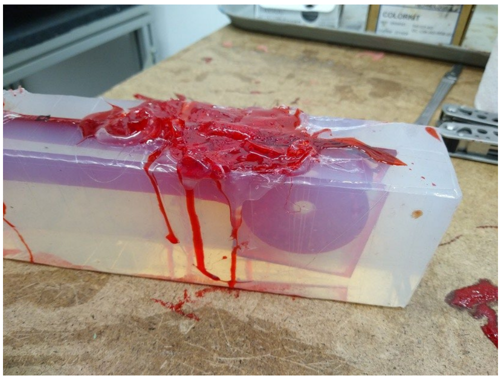

Fig. 26 Casting of R1 after breaking the inlet system

There were also a lot of small air bubbles captured in the arm (Fig. 29). This means that this part is unusable and therefore it is necessary to cast it again.

Fig. 27 Removing the R1 casting from the mold

Fig. 28 Taking away of plexiglass

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Plexiglass is like the core of the mold and creates a slit in the joint part of R1.

Fig. 29 Unexpected bubbles in the casting R1

It was probably a mistake that both parts are cast together in a vacuum chamber. After filling the first mold (part R2), the vacuum chamber had to be vented in order to be able to move the molds and pouring the mixture into the R1 mold. An unnecessarily massive inlet and a hole were formed on the R1 model, while the longitudinal narrow side of the R1 part was free. That was the place where unwanted air bubbles occurred.

Part R2 was removed from the mold without any difficulty. It was also free of defects. Even though it was usable, this part was cast again (Fig. 30).

Fig. 30 Removing the R2 casting from the mold

Although this set of parts R1 and R2 was damaged, they were cleaned (Fig. 31).

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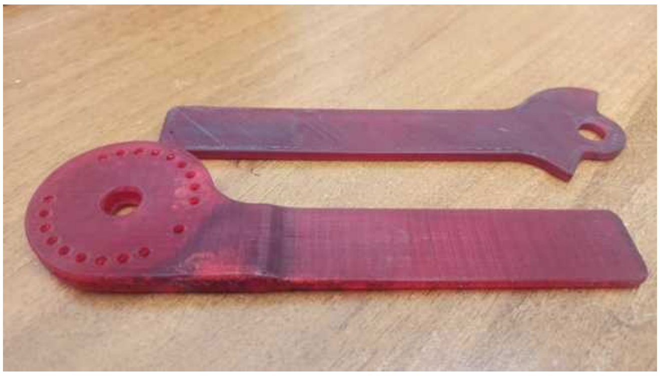

Fig. 31 Set of red arms after cleaning the castings (defective air bubbles can be noticed in the R1 part)

As both parts were manufactured again, the material from which they were cast was also changed. This time the material used was similar to ABS after curing.

CASTING INTO THE SILICONE MOLD (2)

Fig. 32 shows the data sheet of the material used in the second casting attempt.

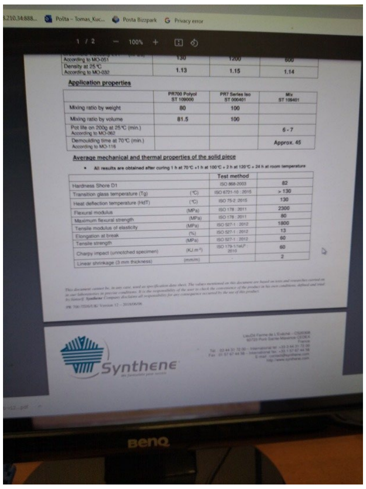

Fig. 32 Data sheet of the material used in the second casting attempt

The molds had to be cleaned before further casting. First, they were cleaned mechanically, the remnants in the vent channels were removed, and the mold was blown with compressed air.

Subsequently, the mold was chemically cleaned with the help of technical alcohol. The cavity of the mold thus cleaned was then sprayed with a separator. The plexiglass was also cleaned

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and sprayed with a separator. As previously mentioned, the plexiglass serves as a core of the mold and creates a gap on the R1 part at the joint.

The molds treated in this way were bound together with adhesive tape. The plexiglass was added to the mold for part R1 so that the part of the arm where the bubbles occurred in the previous case was not in contact with vacuum. The inlet and vent of the mold were also created (Fig. 33).

Fig. 33 Mold of R1 with plexiglass placed at the top

The molds were then placed in an oven and heated at 70°C.

While the molds were heating up, the resin for casting was prepared. According to the resin data sheet, the ingredients were mixed in a ratio of 80: 100. The workability of the compound was achieved after mixing it for about 6 minutes. The individual components were weighed before placing them in the vacuum chamber (Fig. 34).

Fig. 34 Weighing the individual components of the mixture and their insertion in the vacuum chamber

After heating, each mold was placed in the vacuum chamber. When the vacuum value has reached the value -1, the individual prepared components of the resin were mixed. After perfect mixing (about 2 minutes), the mixture was poured into the mold (Fig. 35).

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Fig. 35 Preparing the mixture and pouring it into the mold placed in a vacuum chamber

The filled mold was left in the vacuum chamber for about 4 minutes to fill reliably and to remove all the gaseous bubbles formed in the chemical reaction of the mixture from the casting by vacuum (Fig. 36).

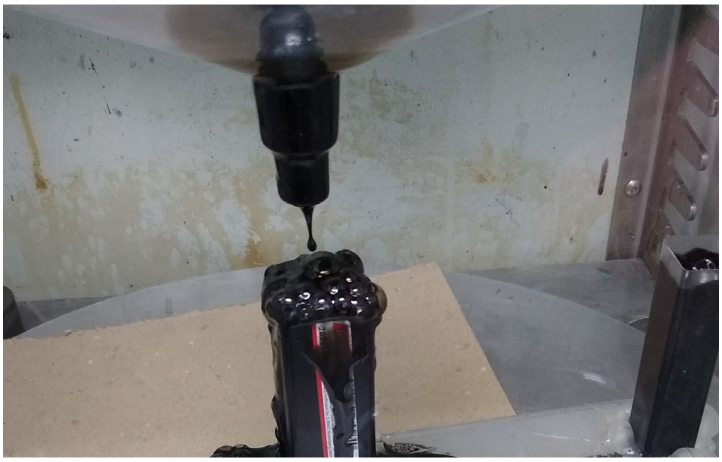

Fig. 36 Vacuum degassing of the R1 mold

After degassing, the filled mold was transferred to the furnace after removing the second mold from it (Fig. 37). The method used for casting into the second mold was the same.

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Fig. 37 Filled molds stored in the oven for resin curing

Both filled molds were allowed to cure in an oven at 70° C for about an hour (the manufacturer recommends at least 45 minutes). After curing the mixture, the molds were removed from the oven. The molds are then allowed to cool on the table at the room temperature. After cooling, the molds were disassembled, and the castings extracted in the same way as in the previous case (Fig. 38). After extraction from the mold, the raw castings did not show any defects or other damages.

Fig. 38 Raw castings extracted from the molds

The raw castings were then put back into the furnace for heat treatment according to manufacturer's recommendations: 1 hour at 70°C, 1 hour at 100°C, 2 hours at 120°C, and 24 hours at room temperature. After removing the inlets and venting, the finished castings were lightly sanded using fine sandpaper and the edges were trimmed (Fig. 39 and Fig. 40).

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Fig. 39 Grinding of castings after removing the inlet and vent

Fig. 40 A set of black R1 and R2 parts after cleaning the castings, without noticeable defects

Fig. 41 shows all R1 and R2 parts placed next to each other.

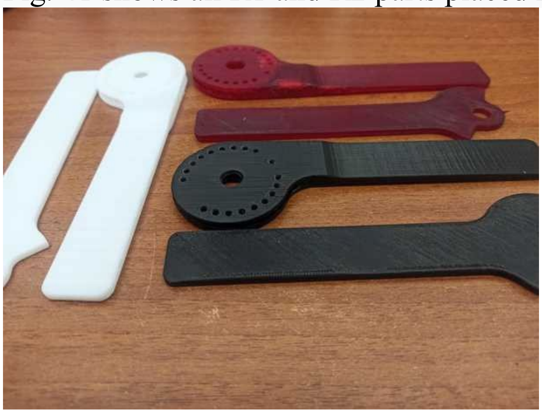

Fig. 41 Cast parts R1 and R2

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The parts R1 and R2 manufactured from different materials are as follows: concrete - WHITE - 3D printing - master model, RED - casting in silicone - failed, BLACK cast in silicone – correct and final version.

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4 Conclusion

Silicone casting can be used in various domains. As part of this project, an effort was made to point out and highlight its use in medicine. As an example, an orthosis was used to support the elbow part of the hand. Casting into a silicone mold was carried out in the company Bizzcom sr.o. in Bučany, Slovak Republic. In the original version, the orthosis is made of metal, but the purpose was to make it as simple as possible so that it was strong, weight-wise, and usable in the rehabilitation of the human body limb. From the realized CAD model, a real 3D model was created by means of a 3D printer as a physical model used for the creation of a silicone mold. Subsequently, two casting experiments were carried out, as in the first one the quality of a part was affected by air bubbles (red version). The second attempt was successful, and the quality of the castings was quite satisfactory (black version). At the same time, the effort to use the separator on individual parts, thanks to which the silicone mold is removed, and the effort in obtaining the silicone mold was that its minimum wall thickness must always be 20 mm in order for the silicone to preserve the shape of the part.

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