

RESIN TYPE INFLUENCE ON MOULDED PARTS FINAL DIMENSIONS

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ABSTRACT. Silicone rubber moulding is a perfect solution to fill the gap between rapid prototyping and prototyping injection moulding. Silicone moulds reproduce the tiniest of details, so the quality of the pattern is critical; they are also a fast and affordable solution for functional prototypes and low volume production. A experimental method using vacuum casting of resin parts in flexible moulds is presented in this paper. During the experimental investigations technological features of casted material, volume of air traps, optimal working parameters and dimensional accuracy of the manufactured parts were studied. Based on these results, the corrective coefficients applicable to CAD dimensions in order to fabricate the master models by SLS were determined.

Keywords: *Rapid Prototyping, Resin injection, Viscosity, Silicone rubber moulds*

INTRODUCTION

The Rapid Tooling (RT) technology has evolved a lot in the last decades. Today it is possible to fabricate a complex pattern and other tooling for casting in a few hours while a casting may take up to several days. In the last decades, many companies have made great investments to improve manufacturing technologies in order to develop new products [1]. These technologies include CAD (Computer Aided Design) software and they are used to design complex geometries and also for solving some problems with high degrees of difficulty, including the medical field [2, 3]. In the last decade, many researches about RP (Rapid Prototyping) and RT (Rapid Tooling) technologies have been released, while the casting of the wax parts in a silicone rubber moulds was less studied [4÷6]. The resin patterns can be obtained at room temperature or in special conditions with good accuracy using vulcanizing silicone rubber moulds. Others author like Yang and Hannula, [7] studied the influence of injection parameters

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on the dimensional stability of resin patterns produced by injection moulding process. In our case, we found the relation between various process parameters and their dependency on other parameters [8]. From all the parameters studied, it was found that the injection temperature is relevant for the dimensional accuracy of the parts. Nowadays, RT technology is the perfect options to solve the problems on resin moulded request by the market. It is estimated that total profits on new products are often reduced by as much as 60% because of the company's inability to get the product market quickly enough [9].

In the last few years, RT technology has evolved toward building moulds that provide up to 40% faster cycles than are possible with conventional technology [10]. That emphasis on productivity accompanies a shift in applications from prototype to full production tooling.

The advantages of flexible moulds are: efficiency, by reducing waste and energy consumption; agility for enable customization and flexibility for the modification and implementation of design concepts [11÷14].

In this paper, a new concept for obtaining flexible moulds together with the CAD model used for optimal dimensioning of rubber moulds is presented.

RESULTS AND DISCUSSION

In order to determine the influence of the resin type used in the manufacture of flexible moulds, measurements of resins moulded parts were achieved using Zeiss Navigator Prismo equipment, according to the sketch shown in Figure 1.

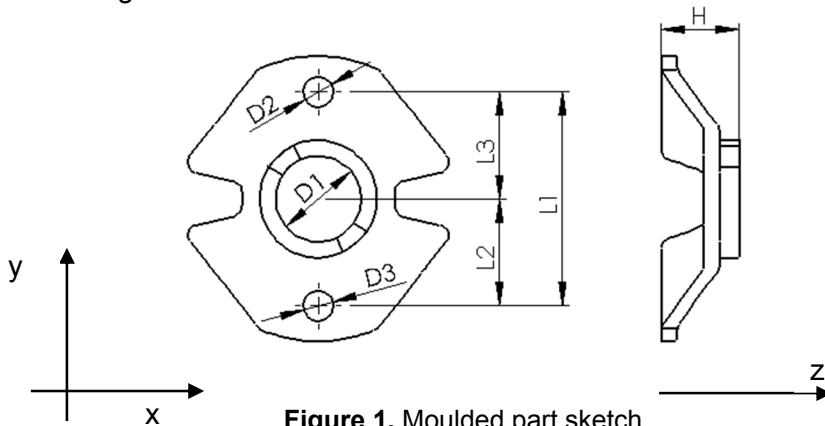


Figure 1. Moulded part sketch.

Additionally, the circularity deviations of diameters $D1 = \varnothing 24$, $D2$, $D3 = \varnothing 8.4$ has been analysed (denoted in the following by $D1 = \text{Dim. 1.1}$, $D2 = \text{Dim. 2.1}$, and $D3 = \text{Dim. 3.1}$) as well as the flatness deviation relative to dimension 7 in measurement sketch (denoted in the following by Dim. 7.1). Dimensions

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measured were compared with CAD model and master model dimensions. Dimensions 1, 2, 3 are measured on the Y axis, 4, 5, 6 are the dimensions measured in the X axis and 7 is the only dimension measured on Z. It can be seen that on the axis X the average deviation is below the 1.5%, on the Y axis it has a value less than 0.65%, while the Z axis deviations occur up to 4%.

Then the percentage contractions of each dimension have been measured by comparing the required dimensions of resins parts and the CAD model, but also in relation to the dimensions of SLS master model. Deviations recorded (mean of 5 values measured) are shown in figure 2 and figure 3.

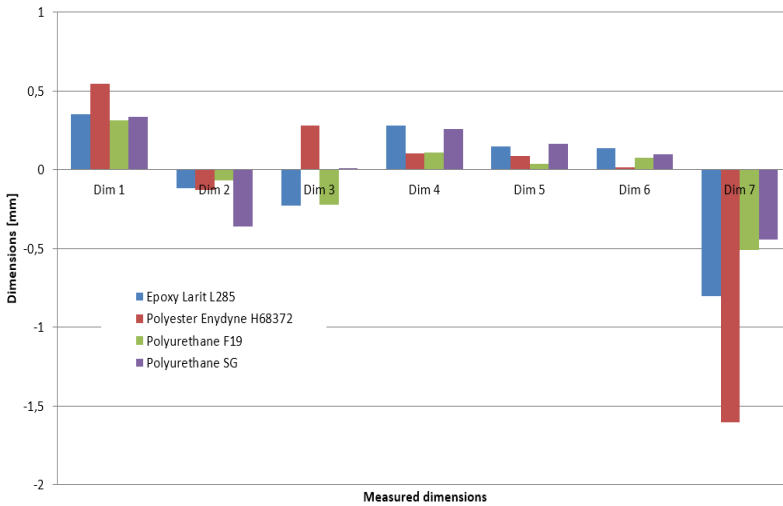


Figure 2. Deviations of resin parts dimensions related to CAD model and SLS master model

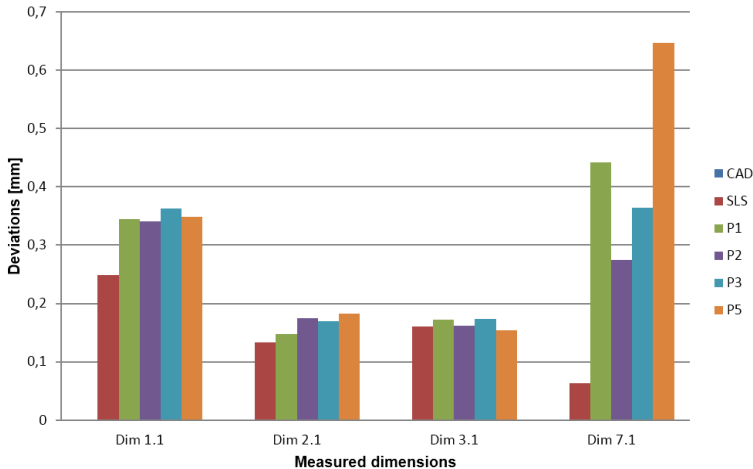


Figure 3. Flatness and circularity deviations

One of the main experimental parameters, important in achieving the flexible moulds, is the viscosity of the resin.

Figure 4 shows the variation in viscosity of the polyurethane resin based on mixing time of the two components of the resin while keeping constant the temperature at which the mould is heated. We observe that, if the times mixing increase, the resin viscosity increase also, due to the polymerization reaction.

Figure 5 presents the variation of viscosity according to the temperature of the mixture, keeping this time constant during the mixing of the components. It is noted that the viscosity increases also with the temperature if the mould is heated.

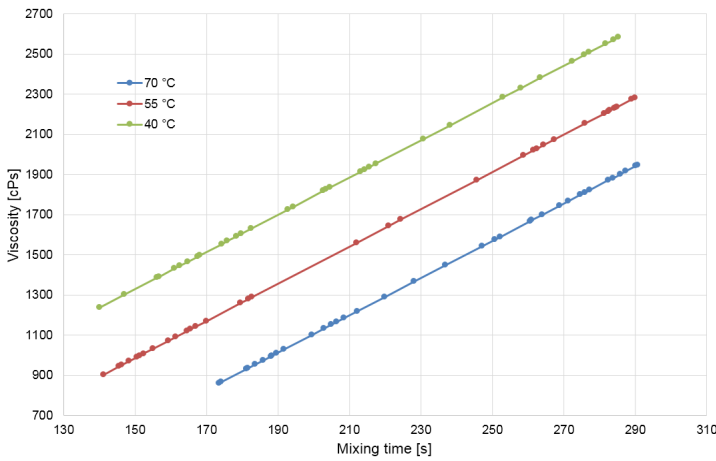


Figure 4. The variation of the viscosity depending on the time of mixing.

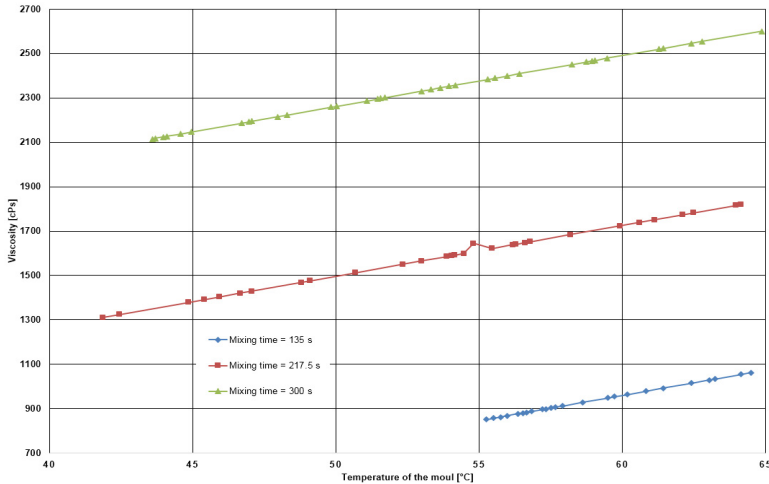


Figure 5. The variation of the viscosity depending on the temperature of the mould.

Experimental determination of resin density after polymerization is also very important in making the final product with the desired characteristics.

Because the resins used in casts are made up of two components (the density is known to each one) it is very difficult to determine the density of the mixture by theoretical methods. For this reason they have been made geometric forms with defined volume, for which the density is easily calculated [16].

After the curing of the resins and weighing each rectangular piece (figure 6) the calculating the volume density was easily determined.

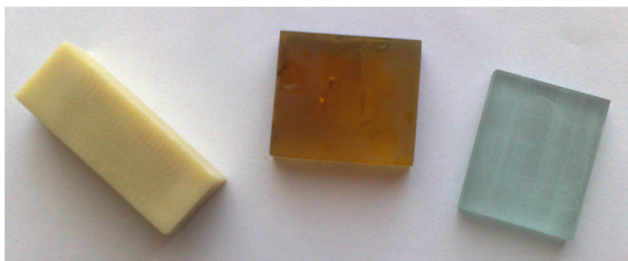


Figure 6. Rectangular pieces well defined volume

In order to determine resin density (ρ) after polymerization, the volume for each parallelepiped was calculated according to the relationship:

$$V = L \cdot l \cdot h \quad (1)$$

where: V – part volume [cm^3]; L – length of the part [cm]; l – width of the part [cm]; h – height of the part [cm].

The experimental values of density after polymerization, $\rho = m/L \cdot l \cdot h$, were showed in table 1 together with the main geometrical parameters of the rectangular obtained pieces.

Table 1. Determination of resins density after polymerization

	Polyurethane F19 resin	Epoxy resin	Polyester resin
Parts dimensions [cm]	L = 3.8360 l = 1.3840 H = 1.2550	L = 2.7980 l = 2.2400 H = 0.4850	L = 2.8200 l = 2.4500 H = 0.7500
The volume [cm^3]	6.6628	3.0397	5.1818
Weight rectangular pieces [g]	7.0995	3.5056	6.0512
Density [g/cm^3]	1.0655	1.1533	1.1678

Experimental determination of density resin after polymerization led to the determination of the weightings of the CAD model [17]. The resin parts dimensions, based on the relationship 3, are presented in table 2.

Table 2. Resin parts dimensions

Sample	D1 [mm]	D2 [mm]	D3 [mm]	L1 [mm]	L2 [mm]	L3 [mm]	H [mm]
CAD model	24.0000	8.4000	8.4000	60.0000	30.0000	30.0000	17.2500
SLS part	23.7158	8.1326	7.5519	59.6925	29.9099	29.7820	17.2502
P. 1.1	24.3669	8.5692	7.8162	60.3033	30.1146	30.1885	16.7955
P. 1.2	24.3929	8.5398	7.8669	60.6776	30.3894	30.2871	16.3860
P. 1.3	24.0076	7.7905	8.2621	59.7460	29.7431	30.0022	16.8426
P. 1.4	24.5381	7.9463	8.8660	60.7144	30.3630	30.3505	15.7217
P. 1.5	24.4680	8.5664	8.0395	59.9678	30.1239	29.8433	16.4893
P. 2.1	24.4064	8.5830	8.2510	59.7979	30.2808	29.5160	15.4736
P. 2.2	24.5332	8.1908	8.7364	60.1256	29.9437	30.1803	15.8147
P. 2.3	24.6897	8.2416	8.8475	60.2111	30.1658	30.0431	15.4242
P. 2.4	24.6918	8.2649	8.8297	60.4084	30.1153	30.2913	15.8715
P. 2.5	24.4099	8.0754	8.7258	59.9858	29.9291	30.0553	15.6499
P. 3.1	24.1477	7.8780	8.3704	59.8086	29.7456	30.0606	17.0035
P. 3.2	24.3205	8.4434	8.0568	60.2403	30.3325	29.9072	16.1595
P. 3.3	24.3405	8.5333	7.9884	60.1635	30.1717	29.9907	16.5231
P. 3.4	24.4162	8.7627	7.9184	60.2740	30.0003	30.2723	17.1941
P. 3.5	24.3462	8.0380	8.5589	60.0662	29.9231	30.1398	16.8124
P. 5.1	24.4812	8.0184	8.5206	60.6067	30.1122	30.4931	16.4912
P. 5.2	24.3312	7.8027	8.4163	60.4418	30.0365	30.4053	16.8814
P. 5.3	24.4570	8.4673	8.1602	60.4080	30.4476	29.9589	16.0380
P. 5.4	24.1264	7.9940	8.4313	59.7262	30.2254	29.5007	17.5102
P. 5.5	24.2779	7.9265	8.5231	60.1156	29.9969	30.1183	17.1020

$$M = \frac{1}{n} \cdot \sum_{i=1}^n x_i \quad (3)$$

where: n – the number of items summed; x_i – measured dimensions which will be summed;

In order to calculate the contraction, the relation 4 was applied.

$$C = \frac{d_{CAD} - d_{masurat}}{d_{CAD}} \cdot 100 \quad (4)$$

where: d_{CAD} – projected dimensions [mm]; $d_{masurat}$ – measured dimensions [mm];

From Table 3 it is noted that the dimensional deviations relative to the CAD model for $\varnothing 24$ mm rate does not exceed the value of 0.55 mm in absolute value (for polyester resin), which is the relative error of less than 2.27%. The Z axis is the biggest errors found in polyester resin which reached 9.29% relative error. On the Y axis we share dimensional deviations from 60 mm up to 0.28 mm for epoxy resin which means maximum relative errors of 0.46%. It was determined experimentally by mixing polyurethane resin viscosity 40 g component A and 60 g component B using rotational viscometer using a disc Rheotest S6 $\varnothing 18$ mm diameter at a speed of 50 rev/min.

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The initial temperature of the two components was increased to 22°C and 30°C temperature in just 45 seconds. Following research it was noted that the Z axis all types of vacuum casting resin used to have high levels of dimensional variation, to around 3 ÷ 9.3% with a maximum deviation of about 8% for the polyester resin. These high values and deviations occurred because of problems closing the moulds, because, if the both halves of the mould are not tightening, the risk that the mould is not filled with resin appears.

Table 3. The relative dimensional error of the resin parts compared to the CAD model

Dimensions	Value [mm]	Resin	Measured average dimensions [mm]	Error	
				[mm]	[%]
D1	24	Epoxy resin	24.3547	+0.3547	1.47
		Polyester resin	24.5462	+0.5462	2.27
		Polyurethane F19	24.3142	+0.3142	1.3
		Polyurethane SG95	24.3347	+0.3347	1.39
D2	8.4	Epoxy resin	8.2824	-0.1176	1.39
		Polyester resin	8.2711	-0.1289	1.53
		Polyurethane F19	8.3310	-0.0690	0.82
		Polyurethane SG95	8.0417	-0.3583	4.26
D3	8.4	Epoxy resin	8.1701	-0.2299	2.73
		Polyester resin	8.6780	+0.2780	3.31
		Polyurethane F19	8.1785	-0.2215	2.63
		Polyurethane SG95	8.4103	+0.0103	0.12
L1	60	Epoxy resin	60.2818	+0.2818	0.46
		Polyester resin	60.1057	+0.1057	0.17
		Polyurethane F19	60.1105	+0.1105	0.18
		Polyurethane SG95	60.2596	+0.2596	0.43
L2	30	Epoxy resin	30.1468	+0.1468	0.48
		Polyester resin	30.0869	+0.0869	0.28
		Polyurethane F19	30.0346	+0.0346	0.11
		Polyurethane SG95	30.1637	+0.1637	0.54
L3	30	Epoxy resin	30.1343	+0.1343	0.44
		Polyester resin	30.0172	+0.0172	0.05
		Polyurethane F19	30.0741	+0.0741	0.24
		Polyurethane SG95	30.0952	+0.0952	0.31
H	17.25	Epoxy resin	16.4470	-0.8030	4.65
		Polyester resin	15.6467	-1.6033	9.29
		Polyurethane F19	16.7385	-0.5115	2.96
		Polyurethane SG95	16.8045	-0.4455	2.58

To avoid this inconvenient it is recommended that future the CAD model to be compensated with some correction factors.

CONCLUSIONS

Thermosetting resins generally are practical in nature at temperatures between 40°C and 70°C responsive to 2 and 5 minutes.

Viscosity of polyurethane resin should be up to a maximum of 1400 cPs, after this value there is a risk that the rapid polymerization of the silicone rubber moulds not to be filled. The amount of 1400 cPs viscosity is reached by mixing the two components of the resin for up to 3 minutes, to a mould temperature of 40°C.

The resin parts are casted in vacuum moulding the silicone rubber on the Y axis deviation does not exceed 1%.

Vacuum castings polyester resin has high dimensional deviations on the 3 axis, Z axis is the most affected with the relative error of 9.29%.

X -axis scaling coefficient is 1, the scaling factor Y-axis has the value 0.99, while the Z-axis scaling coefficient has the value of 1.04 for the epoxy resin Larit L285, 1.1 to H68372 polyester resin, 1.03 for F19 polyurethane resin and polyurethane resin 1.02 for SG95.

EXPERIMENTAL SECTION

For experimental determination of the density, function of body weight, the piece it weighed in air and in a liquid. The relationship used for calculating the density of moulded parts [15], of the resin is:

$$\rho_p = \frac{m_{p_air}}{m_{p_air} - m_{p_water}} \cdot \rho_{water} \quad (2)$$

where:

ρ_p – density of analysed part [g/cm³]; m_{p_air} – piece mass, weighed in air [g]; m_{p_water} – piece mass, weighed in water [g]; ρ_{water} – water density [g/cm³].

The viscosity of the used resins was determined using rotational viscometer Rheotest S6. The unit contains 19 sets of wheels and gears (from 0.3 - 100 rpm), thus allowing optimal choice of scales for measuring structural viscosity and it is used not only for determining the dynamic viscosity of Newtonian liquids but also to conduct thorough examinations on rheological non-Newtonian fluids.

The volumes of bubbles in casting in silicone rubber moulds were made using Shimadzu electronic balance, model AX 120.

Water density was measured using thermo-digital dens meter. The value of measured density is 0.9976 g/cm^3 at $22 \text{ }^\circ\text{C}$.

The density of the water was measured using a thermo-digital dens meter, Anton Paar DMA 33N and the balance used to weighing the parts resin is VWR SE 1202 model.

In terms of measuring the vacuum castings a machine Zeiss Navigator Prismo was used.

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