THE USE OF EPOXY RESINS AS INSERTS FOR INJECTION MOULD

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Abstract*. After the introduction of the Rapid Prototyping (RP) technologies, the processes that were developed or updated to obtain prototype moulds have been referred to as Rapid Tooling (RT) process. The use of CNC (Computer Numerical Control) technology combined with easy to machine materials is a good option to obtain prototype inserts. This is mainly due to some advantages of the CNC machining over the RP technologies used for RT. This work studies some technical and economical feasibility aspects of three different types of epoxy resins available today in the market in the construction of prototype moulds using CNC machining. Some aspects of the manufacturing process such as time and cost (material and machining) for each resin used are analysed and compared. For these analyses, a test part with a pyramid shape was chosen and three pairs of inserts (core and cavity) manufactured and used to inject polypropylene prototypes. Two resins can be considered as successful, with the inserts being obtained in less than 3 days and good injected parts obtained.*

Keywords*. Rapid Tooling, RT, CNC machining, Prototype moulds, Epoxy resins*

1. Introduction

One way to obtain a small batch of prototypes in the same material of the final production parts is to use a prototype mould. Nowadays, the processes used to obtain prototype moulds are called Rapid Tooling (RT), mainly because of the introduction of the Rapid Prototyping (RP) technologies (Jacobs, 1996, Kruth, 1991). Although not using any of the RP technologies (which are based on layer manufacturing) available in the market, the use of CNC (Computer Numerical Control) machining combined with easy to machine materials can be considered as a good option to obtain prototype inserts. This is mainly due to some advantages of the CNC machining over the RP technologies used for RT. Some of these advantages are related to the lower cost of the CNC machine, a better dimensional accuracy obtained, the speed that some materials can be machined and also the vast range of material that can be machined (Kruth *et al*, 1998, Bloor *et al*, 1994).

CNC machining can satisfy the needs of fast free form (complex shape) fabrication in many cases. Recently, the development of tooling for the high speed machining of hard materials and of 5-axis CNC milling has greatly extended the versatility and reduced the time required by material removal processes (Bloor *et al*, 1994, Hassold, 1995). Additionally, with the software (CAD/CAM systems) to define the toolpath becoming more and more user-friendly, CNC machining can be regarded as an alternative for the layered processes. Based in a study involving time-drive cases, Wall *et al* (1992) stated that CNC machining was among the best prototyping alternatives.

It is fair to mention though that, there are some geometric restrictions for CNC machining process. This is because only the regions of an object that can be reached by a tool can be removed. In addition, some extra time in the machining process is required to define cutting tools, fixtures, process planning, toolpath generation using a CAM system and machine set-up. Therefore, with increasingly complicated geometries, the potential for simplification of manufacture created by the new layer manufacturing technologies comes into its own (Bloor *et al*, 1994). However, in the area of tooling manufacturing, this limitation is somewhat minimised because of the inserts geometry. For instance, due to the part extraction requirement, the insert geometry should be oriented/designed in order to not generate undercuts, which is favourable to machining. Related to that, Wilkening (1996) added that, in general, rapid tooling based on RP processes can not compete against High Speed Milling machines when insert geometry is simple enough to be manufactured, for instance, just by milling.

The idea behind to use CNC machining as a RT process is that only the inserts are made of an alternative material, all the other mould components are made of traditional steel alloys (Gomide, 2000, Ahrens *et al*, 2002). This is necessary because a traditional injection moulding machine is used to obtain the prototypes. Therefore, in order to be fast, a standard injection mould needs to be ready to accommodate the prototype inserts.

Epoxy resins are commonly used as materials for prototype inserts (Yang and Ryu, 2001, Lanz *et al*, 2002). They are thermosetting polymers which composition and fillers can vary considerably, and, as a consequence, their cost. There are in the market resins for several applications, such as for production of visual prototypes, scale models, mock ups, pattern models and casting models (see Tab. 1). In addition, some resins have also been used to obtain tools for sheet metal forming and more specifically for injection moulds of thermoplastics. The latter is usually filled with metallic powder (e.g. aluminium) to increase its thermal conductivity. In general, it is observed that the cost of the resins increases with the increase of technical demands for each application field. Therefore, the resin recommended for prototype moulds is quite expensive comparing to the others.

Although some of these materials are suitable for moulds and dies, it seems that their popularity is not very high. This might be due to its cost, but also due to lack of information on how to use them. Lanz *et al*, (2002) pointed out the machinability characteristics of these materials have not been studied in detail.

Recently, Yang and Ryu (2001) presented the development of an aluminium filled plastic composite to obtain mould inserts. Some machining studies were also reported in their work. In another work, Lanz *et al* (2002) presented a machinability study of a commercial epoxy resin also meant to obtain prototype inserts. In both cases, High Speed Machining (HSM) technology was used to machine the resins. This technology is obviously faster than the conventional CNC machining, however, in Brazil, it is still not very popular. A study is then necessary to identify if it is feasible to machine these composite materials using conventional CNC machines.

Another question that arises is related to the application field of the resins available in the market. For instance, one can ask if a specific resin available for injection moulds is always recommended, independent of the number of prototypes required. In other words, whether it is possible to use cheaper resins in the injection process and obtain a small number of prototypes at a lower price.

This work seeks to verify the technical and economical feasibility of three different types of resins available today in the market in the construction of prototype moulds using conventional CNC machining technology. The manufacturing cost (material and machining) and time for each resin used are analysed and compared. For these analyses, a test part with a pyramid shape was chosen and three pairs of inserts manufactured and used in the injection process of polypropylene.

Table 1. Characteristics of the epoxy resins used (Vantico, 2003)

Product Description	**Ren Shape 460**	**Ren Shape 5166**	**Express 2000**
Application	Master models, cubing models, patterns, etc.	High density premium polyurethane grade board for checking fixtures, nickel electroform mandrels and metal forming	Heat resistant epoxy board for injection moulding applications, aluminium filler
Colour	Brown	White	Grey
Density (kg/m^3)	770	1660	1800
Shore-D-Hardness (ASTM D-2240)	60-64	90	91
Compressive Strength (ASTM D-695) (Psi)	2-200	9-500	36-500
Coefficient of Thermal Expansion (TMA) (10-6in/in/°F (22 to 86°F))	32	22	21
Tg by DMA (ASTM D-4065) (°C)	104	109	258
Ultimate Tensile Strength, psi (D-638)	1,800	4,875	9,000
Thermal Conductivity, W/m °K	NA	NA	1

NA- Not Available

2. The Development of the Inserts for Prototype Moulds

2.1. The Epoxy Resins Used

Three commercial resins from Vantico's Ren Shape family were selected as insert material. The main application and some of the material properties available for these resins are presented in Tab. (1). These resins are offered in the market in boards of 400 or 600x1500x50mm. As can be seen only the Express 2000 is recommended as injection mould material. Although the other two resins are not recommended, they were chosen because of their relative good compressive strength and density compared to other resins available in this family. These are important characteristics for injection moulding process. Additionally, the lower cost of the Ren Shape 460 and 5166 might justify some application for tooling where a small number of prototype is required. The Ren Shape 460 was used with success as insert material for a simple tensile test specimen geometry in a previous study (Ahrens *et al*, 2002).

According to Lanz *et al* (2002), the commercial epoxy resin Express 2000 is composed of 51% (wt) of aluminium particles and 49% (wt) of epoxy resin. Unfortunately, it was not possible to find any information about the composition of the other two resins used.

2.2. Experimental Studies of the Machining Parameters

The cutting parameters recommended by the manufacturer for the three resins is presented in Tab. (2). As can be seen, for the Express 2000 resin, it is suggested to use very high cutting speed conditions, which sometimes are out of the conventional CNC machine range. Because of that, a simple test was planned to analyse the machinability of these resins using the available machine. Two parameters were observed, surface roughness and material break-out, when varying the feed. Material break-out was defined by Lanz *et al* (2002), as small fragments of the workpiece material fractured under certain cutting conditions. A flat-end-mill, 10mm diameter, was used to cut a slot 55mm long and 3mm deep, in a range of feed. The tests were carried out in a Cincinnati Milacron Arrow 500 machining centre available in the CEFET-PR (Federal Centre of Technological Education of Paraná)/NuFER (Research Group in Tooling Design and Manufacturing). This machine has a maximum spindle speed of 6000rpm.

Table 2. Machining parameters recommended by the manufacturer (Vantico, 2003)

Ren Shape	Roughing			Finishing		
	n (rpm)	f (mm/min)	f_z (mm/tth)	n (rpm)	f (mm/min)	f_z (mm/tth)
460	1600	1000	0.16	10000	2500	0.12
5166	1600	1000	0.16	10000	2500	0.12
Express 2000	6000 - 10000	6000	0.25 – 0.15	15000	7600	0.25

Key: n - spindle; f - feed; f_z – feed per tooth
Cutters: Roughing – 25.4mm Hog Ball End Mill 4-Flute HS Steel 8% Cobalt
Finishing – 15.87mm Ball End Mill 2-Flute Carbide
Depth: Roughing - varied from 6.35mm to 63.5mm deep with a 40% stepover
Finishing – 3.17mm deep leaving 0.05mm scallop height

Although the manufacturer mentions the use of HS Steel to machine Express 2000, preliminary test showed that the tool wear was considerable after few minutes. It was decided then to use carbide tool. Another preliminary machining test with this resin was carried out using a similar workpiece geometry mentioned before, a 10mm end-mill and cutting speed of 126m/min (4000rpm). In this test, the feed varied from 500 to 3000mm/min (feed per tooth-f_z from 0.06 to 0.38mm/tooth), with increments of 500mm/min. This test showed that this material is very prone to break-out (a picture of this test is presented in section 3). Based on the results of this test and on Lanz *et al* (2002) conclusion, which showed that feed per tooth has a great effect on break-out, new tests were planned reducing f_z.

Table (3) presents the cutting conditions for the three resins used in this study. Two tests were performed for each resin, one using the recommended parameters and the other increasing the cutting speed in 20% for the resin 460 and 10% for the 5166. Two different cutting speeds were tested for the Express 2000.

The surface roughness (Ra) was measured using a stylus-type profilometer (Zeiss TSK-E30A) and the break-out was characterised with a close-look inspection.

Table 3. Machining test conditions for the three resins

460				5166				Express 2000			
Test 1		Test 2		Test 1		Test 2		Test 1		Test 2	
Vc (m/min)	f_z (mm/tth)	Vc (m/min)	f_z (mm/tth)	Vc (m/min)	f_z (mm/tth)	Vc (m/min)	f_z (mm/tth)	Vc (m/min)	f_z (mm/tth)	Vc (m/min)	f_z (mm/tth)
126	0,03	150	0,03	126	0,03	141	0,03	94	0,03	126	0,03
(4000rpm)	0,06	(4800rpm)	0,05	(4000rpm)	0,06	(4500rpm)	0,06	(3000rpm)	0,05	(4000rpm)	0,04
	0,09		0,08		0,09		0,08		0,07		0,05
	0,13		0,10		0,12		0,11		0,08		0,06
	0,16		0,13		0,15		0,14		0,10		0,08
	0,19		0,16		0,19		0,17				
	0,22		0,18		0,22		0,19				
	0,25		0,21		0,25		0,22				
	0,28		0,23		0,28		0,25				
	0,31		0,26		0,31		0,28				

Key: f_z - feed per tooth (mm/tooth); Vc - cutting speed (m/min); Tool diameter - 10mm; Tool material - HSS for resin 460 and 5166 and carbide for Express 2000; Depth of cut – 3mm

2.3. Prototype Part and Insert Geometry

In order to test the resins as insert materials a test part was proposed. Some considerations influenced the geometry of this part. Initially, the insert size was limited by the standard mould plate slot to be used, which was 70x75x130mm. Another point was the limitation of the board thickness available in the market (50mm). The part geometry was thought to facilitate any dimensional analysis of the moulding injected in the different resins. For this initial study, a relatively simple geometry was chosen, which complied with the above requirements. The CAD system SolidEdge, from

Unigraphics Solution Inc, was used to create the part and insert geometry. Figure (1b) presents the pyramidal shape part designed, with three steps and 2mm constant wall thickness. The dimension of the pyramid base is 94x49mm and the total height is 14mm (4mm for each step).

Following the results of a previous study (Ahrens *et al*, 2002), the polypropylene H301 commercialised by Braskem was chosen as the test part material. This is a commonly used material in many industrial applications.

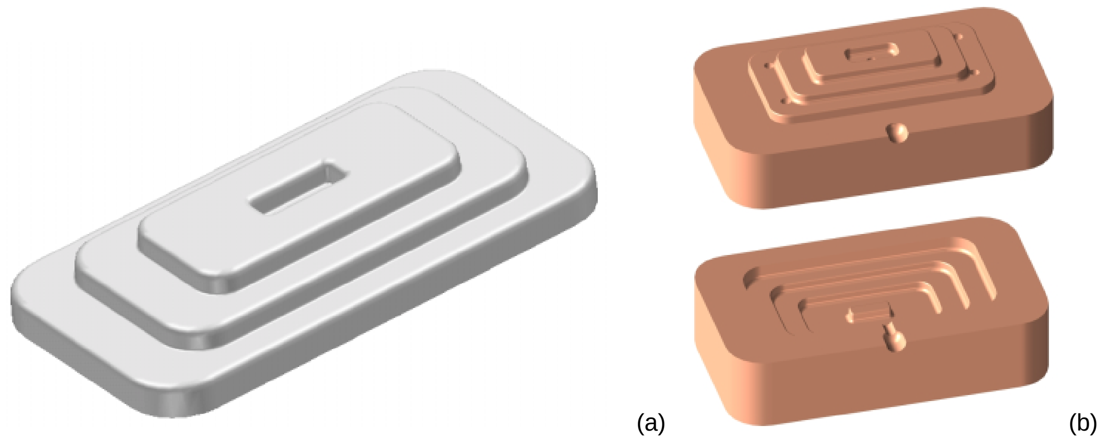

Figure 1. Test part geometry (a) and mould inserts – core and cavity (b)

Based on the part geometry and on the size and the position of the slot in the mould plates, the core and cavity inserts were designed (Fig. 1b). Because of the depth of the mould slot (70mm) and the thickness of the resin board available (50mm), it was designed a metallic base of ABNT 1045 steel for the inserts. This solution not only solved the height problem but also allowed an economy in resin material. This metallic base can be used for any other part geometry in the future. Figure (2) shows the insert and the base assembly.

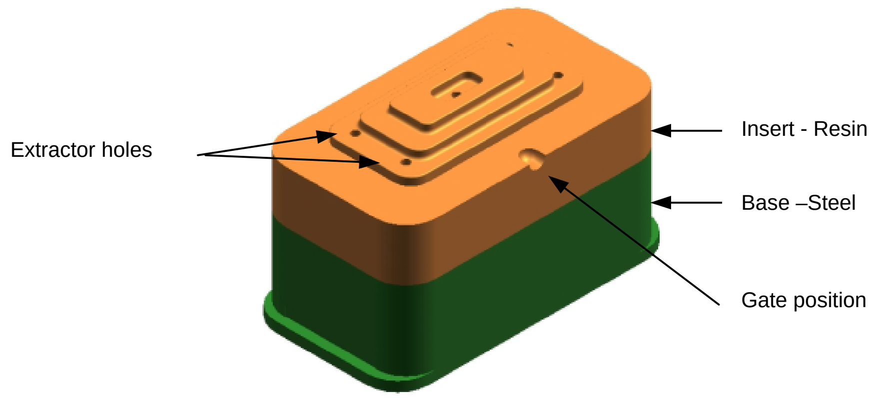

Figure 2. Mould insert and metallic base designed to reach the required insert height

For the part geometry designed, the best gate position (more adequate) would be in the middle of the part. However, the standard mould used was a two-plate mould, each plate containing two slots to allocate inserts. Therefore, it was necessary to design a short runner system to connect the sprue to the gate, which was positioned at the lateral of the part (Fig. 2). With the gate in this position, some welding line can be expected in the opposite side of the part. As there is not enough information about the use of these resins as inserts for injection moulding, the gate size was unknown. It was decided to design a small gate and, according to the injection behaviour, to enlarge it later if necessary. A semi-cylindrical shape gate, 2.5mm deep, was defined using a ball nosed mill of 3mm.

Another information not available was the extraction force needed and the number of extractor pins to be used. Based on the part geometry and on the surface finishing intended (no polishing would be used), it was decided to use 5 extractor pins positioned as presented in Fig. (2).

Draft angle was also another parameter that we have no information. As the previous study (Ahrens *et al*, 2002) carried out with one of these resin (Ren Shape 460) did not involve the use of a core insert, there was not much information available in this issue. A draft angle of 1.5^{o} was applied based on a recommendation for stereolithography inserts (Gomide, 2000).

2.4. Inserts Manufacturing Process

Based on the geometry of the inserts, the software PowerMill, from Delcam International plc, was used to generate all the tool paths required for the machining. All the three insert pairs were machined using the same CNC programs, just altering the cutting parameters. This was done to allow machining time comparison between the resins. The PowerMill machining predictor was used to find the machining time. In addition, the time was also estimated for aluminium 5052 to allow comparison. Although the recommended aluminium for mould is usually the 7075 alloy (Menges and Mohren, 1993), the 5052 alloy was selected because it would be adequate for a prototype mould and cost a quarter of the 7075 alloy. The machining conditions for the aluminium alloy was for roughing Vc=150m/min, f_z=0.13mm/tooth, and for finishing Vc=200m/min, f_z=0,02-0.07mm/tooth, using HS Steel.

Both, the core and cavity, were machined in a similar process sequence, which involved three different stages of CNC machining (in a vice) and one outside the machine. Table (4) summarises the CNC machining process of the inserts, including the tool list with a description of the machining operation and the cutting parameters (spindle and feed per tooth). The cutting parameters were based on the manufacturer recommendation (Tab. 2) and also in the machining test results presented later (section 3). The tool material used was HSS for the resins 460 and 5166 and Carbide for the Express 2000. All inserts were also machined in the Cincinnati Milacron Arrow 500 machining centre. Figure (3) shows one of the inserts being machined.

Table 4. Summary of the CNC machining process for all core inserts

Stage	Tool (mm)	Description	Spindle (rpm)			Feed per tooth(mm/tooth)		
			460	5166	Express	460	5166	Express
1	EM ∅20	Outer contour	2000	2000	6000	0.13	0.13	0.03
		General roughing	2000	2000	6000	0.13	0.13	0.03
	EM ∅10	Split surface finishing	4000	4000	6000	0.08	0.08	0.02
		Corner finishing of first step	4000	4000	6000	0.08	0.08	0.02
	EM ∅6	Cavity roughing	6000	6000	6000	0.04	0.04	0.02
	EM ∅4	Top face step finishing	6000	6000	6000	0.03	0.03	0.02
	BN ∅3	Draft surface finishing (steps)	6000	6000	6000	0.02	0.02	0.02
	D ∅3.8	Extractor holes	6000	6000	6000	0.03	0.03	0.005
	R ∅4 h7	Reaming	6000	6000	6000	0.03	0.03	0.002
	BN ∅8	Runner	5000	5000	6000	0.06	0.06	0.02
2	EM ∅20	Face Milling (lateral)	2000	2000	6000	0.13	0.13	0.03
3	FM ∅63	Face Milling	640	640	2400	0.50	0.50	0.008
	EM ∅20	Outer contour	2000	2000	6000	0.13	0.13	0.03
	D ∅6,5	Holes for tapping	6000	6000	6000	0.05	0.05	0.004

Key: EM-End-Mill; BN-Ball Nose; D-Drill; R-Reamer; FM-Face Milling

The cavity inserts were machined using the same tools and cutting conditions, therefore it is not presented here. The machining time is going to be different and is presented in section 3.

All finishing strategies were planned to avoid any post-processing (surface finishing) after the CNC machine. A z-constant machining strategy was applied to finish the lateral walls of the steps, with a stepdown set to 0.05mm. Two machining operations were performed manually after CNC, tapping and drilling. After this, the inserts were ready to be assembled in the mould.

Figure 3. The CNC machining of the insert (Ren Shape 5166)

2.5. The Injection Process

After machining, the inserts were assembled in the mould plates as shown in Fig. (4) and were ready for injection. The injection machine used was an ARBUG 320S 500-150 available in the CIMJECT/UFSC and, as mentioned before, the polypropylene 301 was used to produce the prototypes. In this work, it was not intended to study the injection process in detail (such as: mould life, material and mechanical properties of the moulding, best processing parameters, etc). The objective was only to determine whether it was possible to obtain good prototype parts with these insert materials. A more detailed study is under way and will be presented in another work. However, some important points related to the injection process were observed.

Figure 4. Core and cavity inserts assembled in the mould plates (Express 2000 inserts)

As there was not much information about the injection parameters to be used for the combined insert and polymer materials, some initial try-outs were necessary until a fully injected part was obtained. Table (5) presents a summary of the injection parameters used in this study for the three resins. The prototype parts were measured using a digital vernier calliper with a resolution of 0.01mm to analyse any dimensional variation.

Table 5. Summary of the injection parameters used in the injection of polypropylene

Resin	Part Number	Injection Pressure (MPa)	Clamping Force (ton)	Injection Temperature (° C)	Injection Speed (mm/s)	Holding Pressure (MPa)
460	1-8	20	75	210	75	
	9	22.5	75	195	75	
	10	26	75	183	75	
	11	26	75	175	75	
5166	1-5	26	75	175	75	
	6	26	75	180	85	
	7	28	75	180	85	
	8	30	75	180	85	
	9	30	75	185	85	
	10	32	75	185	90	
	11	32.5	75	185	90	
	12-23	33	75	185	85	
Express 2000	1-8	33	75	185	100	
	9	34	75	185	100	
	10	35	75	185	100	
	11-20	36	75	190	100	
	21-33	36	75	190	100	26

3. Results

As mentioned before, the preliminary machining test carried out with the Express 2000 showed that this material is prone to break-out. Figure (5) shows a picture of this preliminary test. For the cutting speed of 126m/min, the material started to break-out at the tool exit at the feed of 1000mm/min (0.13mm/tooth). As the feed increases (after 2500mm/min), the break-out started to damage also the lateral wall (2mm) of the machined slot.

The results of the experimental studies are presented below. Table (6) presents the results of the surface roughness (Ra) of the machining test carried out with the three resins. No break-out effect was observed for the resins 460 and 5166. For the Express 2000, only at around 500mm/min (0.04mm/tooth), tiny pieces of resin started to be removed at tool exit.

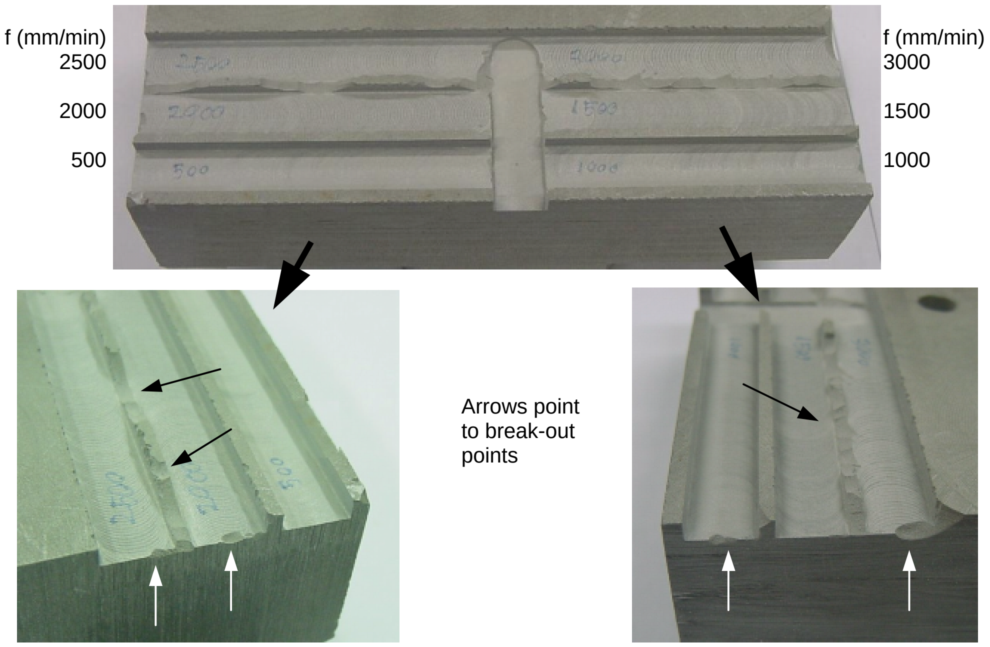

Figure 5. Workpiece test showing the Express 2000 break-out

Table 6. Machining test results - surface roughness

460				5166				Express 2000			
Test 1		Test 2		Test 1		Test 2		Test 1		Test 2	
f_z (mm/tth)	Ra (μm)	f_z (mm/tth)	Ra (μm)	f_z (mm/tth)	Ra (μm)	f_z (mm/tth)	Ra (μm)	f_z (mm/tth)	Ra (μm)	f_z (mm/tth)	Ra (μm)
0,03	2,00	0,03	2,8	0,03	1,00	0,03	1,8	0,03	2,08	0,03	2,00
0,06	2,00	0,05	2,5	0,06	1,80	0,06	2,0	0,05	2,10	0,04	2,69
0,09	2,00	0,08	2,6	0,09	1,55	0,08	1,7	0,07	2,30	0,05	2,43
0,13	2,15	0,10	2,4	0,12	1,60	0,11	1,9	0,08	2,40	0,06	2,82
0,16	2,15	0,13	2,5	0,15	1,70	0,14	1,9	0,10	2,90	0,08	3,30
0,19	2,50	0,15	2,9	0,19	1,75	0,17	2,3				
0,22	2,25	0,18	3,0	0,22	2,20	0,19	2,0				
0,25	2,20	0,20	3,0	0,25	1,90	0,22	2,3				
0,28	2,20	0,23	3,1	0,28	2,20	0,25	2,2				
0,31	2,50	0,25	3,4	0,31	2,30	0,28	2,3				

Key: f_z - feed per tooth (mm/tooth) ; Ra - Surface Roughness

Table (7) presents the CNC machining time for the different insert materials. Besides the CNC machining, some extra time should be added. First, a time related to some process operations, such us: cutting the blank, machine set-up, tool pre-setting and manual machining after the CNC processing. This time was estimated as approximately 150min. Additionally, it is necessary to add the time to generate the CNC programs in the CAM system, which was around 180min each (core and cavity). The total time is also presented in Tab. (7).

Table 7. Machining time for the different insert materials

Inserts	Resins	Stage 1		Stage 2	Stage 3		CNC Machine Time (min)	Total Time (min)	Relative Cost
		Roughing (min)	Finishing (min)	Roughing (min)	Finishing (min)	Drilling (min)			
Core	**460**	5,3	209	0,3	2	0,3	**216,9**	**547**	**1,00**
	5166	5,3	209	0,3	2	0,3	**216,9**	**547**	**1,05**
	Express 2000	14	263	1	7	1	**286**	**616**	**1,30**
	Al 5052	8,3	251	0,6	6	0,6	**266,5**	**596**	**1,14**
Cavity	**460**	7	238,5	0,3	3	0,3	**249,1**	**579**	**1,00**
	5166	7	238,5	0,3	3	0,3	**249,1**	**579**	**1,04**
	Express 2000	20	278,5	1	7	1	**307,5**	**637**	**1,26**
	Al 5052	8	281,5	0,6	6	0,6	**296,7**	**627**	**1,13**

For the cost analysis, a relative cost was defined. The total cost to manufacture the core insert in the resin 460 was taken as 1 and the others were calculated from that. The relative manufacturing cost of each insert was obtained adding up the following cost parts: the CNC machine, the CAD/CAM programming, the resin and also the cost of one technician to carry out the extra operations described before. The final relative cost to manufacture each insert is presented in Tab. (7). The material cost was provided by local dealers.

The Ren Shape 460 inserts presented some problems in the injection process. During the procedure to find some adequate injection parameters, the injected part started to stick to the insert surface, close to the gate. Some completely filled parts were produced but presented high warpage and surface damage close to the gate. After six shots, the cavity lost a bit of resin in the middle of the part (it stuck to the moulding) and after eleven shots the core lost a bit close to the gate. The injection was aborted after that. Figure (6) shows the insert regions that were damaged during injection. Because of that, it was not possible to inject any good part with this resin.

Figure 6. Damages in the inserts of the resin 460

Because of a problem in the machining process, the gate dimension of the insert made with the resin 5166 was smaller than expected (1.7mm deep instead of 2.5mm). This difference was enough to make the injection process unsuccessful for many variation of the injection parameters. When this problem was realised, the gate dimension was corrected (enlarged to 2.7mm) and 9 parts were successfully injected. The resin Express 2000 did not presented any problem and 22 parts were fully injected. Figure (7) shows some of the prototypes injected. Table (8) presents a summary of the dimensional results for the prototypes considered as good parts. The inserts made with the resin 5166 and Express 2000 did not suffer any damage during the injection tests.

Figure 7. Some prototypes injected in the epoxy resin mould (Express 2000 inserts)

Table 8. Summary of the injected prototypes dimensional results

Resin	Position	1º Step Length (mm)	1º Step Width (mm)	2º Step Length (mm)	2º Step Width (mm)	3º Step Length (mm)	3º Step Width (mm)
5166	Average	92,12	47,76	72,26	35,77	52,35	23,81
	Standard deviation	0,14	0,06	0,08	0,04	0,07	0,04
Express 2000	Average	92,19	47,75	72,26	35,75	52,33	23,77
	Standard deviation	0,07	0,05	0,06	0,07	0,07	0,07

4. Discussion

The break-out behaviour observed at the tool exit during the machining test of the Express 2000 was also reported by Lanz *et al*, (2002). They concluded that, during machining, the resin material is removed primarily by brittle fracture due to the brittleness of the epoxy matrix. As can be seen in Fig. (5), when the feed per tooth increases the material starts to break-out considerably. This trend agrees with that presented by Lanz *et al*, (2002).

The surface roughness results (Tab. 6) shows that, for the same cutting conditions, resin 460 presented a rougher surface than resin 5166. This is likely to be due to the material density, as resin 5166 is denser than resin 460 (see Tab. 1). The higher roughness of the resin Express 2000, when compared to the resin 5166, was unexpected. This result might be related to the lower cutting speed used for the former, due to the CNC machine limitation.

Because the cutting conditions were the same, the time to machine the insert in resin 460 and 5166 was the same. The total time to obtain the insert pair in these two resins was (1126min ≈ 18.8h), 10% lower than the Express 2000 (1253min ≈ 20.9h). As expected, the major contribution to the CNC machining time was the finishing step. Part of this came from the refined cutting conditions used for the z-constant strategy to finish the step laterals. The total estimated time for the aluminium 5052 was similar to the Express 2000. Using HSM, Yang and Ryu (2001) reported that the machining time of their epoxy resin, similar to the Express 2000, was 7 times faster than an aluminium alloy. However, in this study, the machine time for the Express 2000 could not be reduced further because of the break-out effect when increasing the feed per tooth and keeping the lower cutting speed. In general, the time results show that, for the insert geometry tested and using a conventional CNC machine, the insert pairs were ready for injection in less than 3 days (considering an eight-hour shift).

Although the relative cost of the insert material are quite different (resin 460=1, resin 5166=1.99, Express 2000=4.52 and aluminium alloy=2.07), the difference in the total cost was not that pronounced. This was observed because other manufacturing costs attenuated the weight of the material cost. As expected, the insert made with Ren Shape 460 is the cheapest. The one made with Ren Shape 5166 was around 25% cheaper than the Express 2000 and 9% cheaper than the aluminium alloy. The Express 2000 insert was more expensive than the aluminium alloy.

The inserts of the Ren Shape 460 suffered permanent damage during injection. Some points should be considered when analysing this problem. Because it was the first insert tested, the temperature of the injection was set too high (see Tab. 5) and this might have contributed to weak the resin. The problem might also be caused by an insufficient draft angle (1.5^{o} for all resins), combined with a higher surface roughness mentioned before. A thermal expansion 30% higher than the other two resins might also have contributed to hold the moulding during extraction. Additionally, this resin has lower strength. It is likely though, that the cause was a combination of these aspects.

Fourteen shots were required before the incorrect gate dimension of the Ren Shape 5166 was detected. This resins endured well this job, but this could have caused a permanent damage to the inserts. For the Express 2000, twelve shots were required to find adequate injection parameters. Therefore, it became clear that, in order to get good injected prototypes with few try-out shots, without damaging the inserts, a detailed study in the injection process of this insert materials is capital. A machine operator with a very good experience in the injection process would also help in this process. Based on all these observations, the resin 460 should not be discarded completely as insert material but further study must be considered.

The insert surface finishing obtained in the machining process of resin 5166 and Express 2000 did not cause any problem during the injection process. This suggests that, when fine machining parameters are used, no finishing stage after the CNC machine is required for these inserts to obtain ordinary prototypes.

The dimensional results of the prototypes injected in the inserts made with resins 5166 and Express 2000 (Tab. 8) showed that both resins produced parts with the same dimensional quality. Adding the lower resin cost to that and it can be stated that the resin 5166 can be considered a good option for prototype inserts. A study considering insert life is required to have a better characterisation of this material.

5. Conclusions

This work represents a first step in the direction of a better understanding of the use of different epoxy resins as material for prototype mould. Three different epoxy resins available in the market have been tested for the injection process, the Ren Shape 460, Ren Shape 5166 and Express 2000. Although just the last one is recommended for the injection process, two resins can be considered as successful, Ren Shape 5166 and Express 2000. The inserts were obtained in less than 3 days and good injected parts obtained. The manufacturing cost of the insert made with former resin is 25% less than the latter though, which suggests that it is a good option as insert material. The Ren Shape 460 presented some strength problems during injection process but more study is required to be conclusive about it application as insert material.

The conventional CNC machine used did not allowed the use of faster cutting conditions for the Express 2000. This is due to the brittleness of this resin, which makes it prone to break-out when using low cutting speed combined with higher feed. Because of that, the insert pair made with this material was the most expensive.

It was observed that, in order to get good injected prototype parts in these epoxy inserts, a machine operator with a very good experience in the injection process is recommended. It is not a trivial process to get the injection parameters right in the first shots.

Many points remain to be studied, therefore more research is needed in order to have a better characterisation of the epoxy resins tested for prototype mould application. This characterisation is important in order to increase the range of materials that can be used.

6. Further Work

Some of the points that remain to be studied are: the need for a better gate and draft angle dimensioning, a study in the machinability of small features and details in the inserts, a better definition of the injection parameters for each pair of mould and moulding material, an analysis of the resin behaviour in the injection of different polymers, the changes in material properties of the parts injected in such prototype mould, mould life and others.

7. Acknowledgements

The authors would like to thank Mr. Flavio Braga, from Maxepoxy S.A., for providing some resin samples used in this study. Thank is also due to Prof. Carlos H. Ahrens from CIMJECT/UFSC and also to Prof. José A. Foggiatto and Valter E. Beal, for the co-operation in the injection tests. One of the authors (MMM) would like to thank CNPq-Brazil for a research scholarship in the PIBIC program.

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