PROCESS PERFORMANCE MONITORING IN PEWTER MANUFACTURING

Hamidon Musa
Thean Chan Tan

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

Abstract

This paper reports a study on the casting parameters of pewter based on the Taguchi Approach. The quality attributes investigated are shrinkage, hardness and microstructure. The paper also reports a study on minimum section thickness producable by gravity casting and centrifugal casting of pewter components. Additionally, the paper presents results of a study on finish turning of pewter.

1.0 INTRODUCTION

Pewter finds wide application in the decorative industry such as for souvenir and craft items. Among its attractive attributes are relative softness and ease of machining as well as low cost. The pewter industry is rather well established either as small-scale or larger enterprises. However, scientific investigation and documentation on pewter processing is limited.

In the first investigation (study 01), the objective is to determine the influence of process parameters on the shrinkage and hardness of castings. Steel moulds are used to cast cylinders each measuring 34.85 mm in diameter and 100 mm in length. The microstructure produced is also studied. For the second investigation (study 02), the aim is to determine the minimum section thickness that can be produced in pewter under two casting conditions : gravity and centrifugal casting. Tests are conducted at two temperatures, < 240^0C and > 280^0C. Circular plates of 215 mm diameter and of variable thickness are cast in moulds made of silicone rubber. For the third study (study 03), the objective is to identify machining parameters that influence surface finish of pewter and to identify the optimum conditions that will give the best surface finish quality. Turning is employed as it is the most important machining process in pewter manufacturing.

2.0 EXPERIMENTATION AND RESULT

The Taguchi Method is employed to design and analyse for studies 01 and 03. The stages involved are planning, designing, experimentation and analysis. The Taguchi approach is used to analyse the contribution of each factor to a certain quality attribute studied. It is also used to determine optimum process condition in order to allow the best result for a particular quality attribute of interest. The theoretical result at this optimum condition can be established, and then checked experimentally in a confirmation test.

For the study on casting parameters (study 01), the independent variables (or factors) investigated are the effect of pouring temperature, cooling rate and pewter composition. For each factor, two levels of values are used as shown in Table 1. The corresponding orthogonal array used for this study is the $L_4(2^3)$-OA [1]. Table 2 shows the assigned factors for each of the four trials conducted. Table 2 also gives results for diametral shrinkage and hardness obtained for each of the trials.

Table 1 Factors and levels for casting study

Independent Variables (Factors)	Level 1	Level 2
A ; Pouring Temperature (^{0}C)	< 240	> 280
B ; Cooling Rate	Normal (atmosphere)	Fast (water cooled)
C ; Composition (%)	3 Sb, 1 Cu, 96 Sn	3 Sb, 2.5 Cu, 94.5 Sn

Table 2 Assignment of factors and results obtained

Trial	Factors			Dependent Variables	
	A	B	C	Diametral Shrinkage (%)	Hardness (VHN, 5 kg load)
1.	1	1	1	0.7	17.4
2.	1	2	2	1.5	17.9
3.	2	1	2	1.0	17.7
4.	2	2	1	2.1	17.6

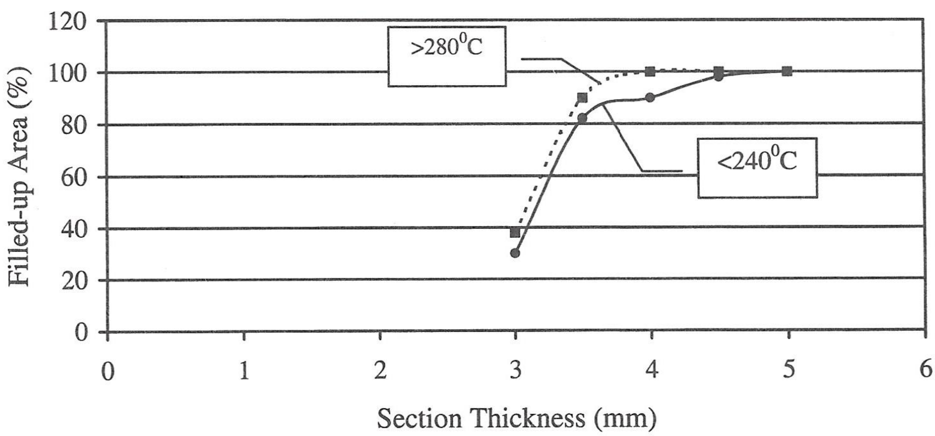

Fig. 1 Percentage area filled-up at varying section thickness (gravity casting)

For the study on minimum section thickness (study 02) the percentage of area filled up by pewter at different mould thickness in gravity and centrifugal casting is shown in figures 1 and 2 respectively.

For the surface finish study (study 03), the factors investigated are feedrate, spindle speed, depth of cut, use of coolant and tool nose radius. Additionally two possible interactions are tested, namely between feedrate and spindle speed, designated as AxB, and between depth of cut and spindle speed, designated BxC. As in study 01, two levels of values are used for each of the factors as shown in Table 3. The orthogonal array used for this study is the $L_8(2^7)$-OA as shown in Table 4, [1]. Also shown are the assigned factors for each of the eight trials conducted. Table 4 also gives results for the surface finish obtained from each of the trials.

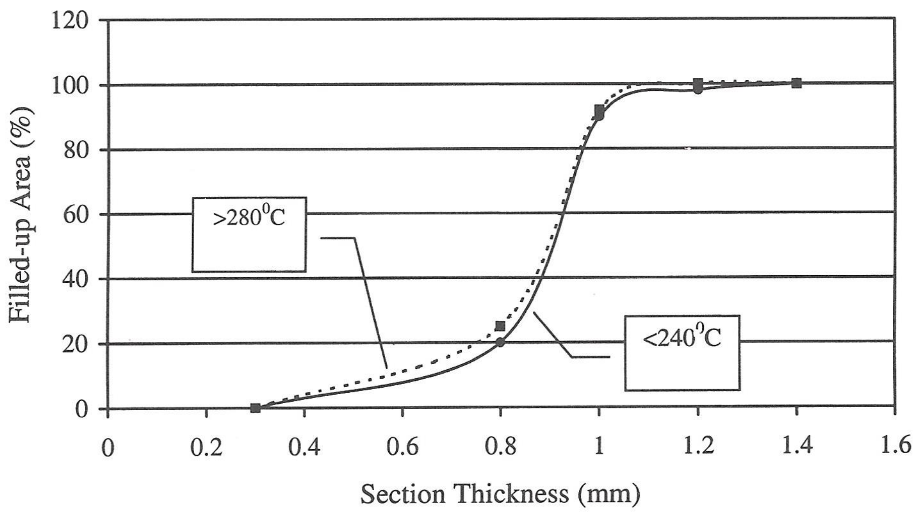

Fig. 2 Percentage area filled-up at varying section thickness (centrifugal casting)

Table 3 : Factors and levels for surface finish study

Independent Variable (or factors)	Level 1	Level 2
A ; Feedrate (mm/rev)	0.2	0.5
B ; Spindle Speed (rpm)	500	800
C ; Depth of Cut (mm)	0.4	1.0
D ; Coolant	on	off
E ; Nose Radius (mm)	0.2	0.6

Tabel 4 : Assignment of factors and results of surface finish

Trial	Factors							Surface Finish, Ra (μm)
	A	C	AxC	B	D	BxC	E	
1.	1	1	1	1	1	1	1	5.1
2.	1	1	1	2	2	2	2	5.6
3.	1	2	2	1	1	2	2	5.7
4.	1	2	2	2	2	1	1	5.2
5.	2	1	2	1	2	1	2	13.3
6.	2	1	2	2	1	2	1	12.9
7.	2	2	1	1	2	2	1	15.2
8.	2	2	1	2	1	1	2	12.4

3.0 ANALYSIS AND DISCUSSION

For study 01, the analysis of variance (ANOVA) shows that cooling rate gives the highest contribution (77%) to shrinkage, followed by pouring temperature (21%). However, the overall shrinkage in pewter casting is low, diametral shrinkage being less than 2.5%. This can be explained by the fact that pewter is mainly made of tin which has a low shrinkage of 2% and the fact that antimony acts like water in the sense that it contracts on melting and expands on solidifying. Analysis on the main effects of each factor shows that the optimum condition for minimum shrinkage can be achieved at lower pouring temperature, low rate of cooling and by choosing pewter with 2.5% Cu as opposed to 1% Cu. It is observed that this condition also gives rise to reduced porosity. This can be explained by the fact that at high pouring temperature, the metal needs a longer time to solidify and takes the shape of the mould and hence the molten metal has time to fill up cavities produced during solidification. The theoretical shrinkage value at this condition is given as 0.5%. However, confirmation test gives a slightly higher value of 0.8%.

For hardness performance, the ANOVA analysis indicates that the copper content in pewter gives the highest contribution (69%), followed by cooling rate (31%). It is known that copper increases the hardness of pewter but decreases its formability. If the copper content is too high, it becomes brittle and gives rise to defect during machining. The hardness of the alloy can be explained by observing its microstructure. Pewter is made up of three phases namely Cu_6Sn_5 needles, eutectic matrix Sn-Cu_6Sn_5 and solid solution of Sb in Sn. The needle-like Cu_6Sn_5 structures, which act as reinforcement, increase at higher cooling rate. A high cooling rate will also give rise to a fine eutectic phase because the dendrites do not have sufficient time to grow in size. This also results in increased hardness [2]. Microstructures of two of the cast specimens are shown in figures 3a and 3b.

(a) Trial 2

(b) Trial 4

Figure 3 : Microstructure of specimens for casting study

From Figures 1 and 2, it can be said that the minimum thickness that can be produced in gravity casting of pewter is 5 mm. In the case of centrifugal casting, it is about 1.4 mm thick. It should be noted that the ratio of the diameter of the part to its thickness is 43 : 1 in the case of gravity casting and 153 : 1 in the case of centrifugal casting. The general effect of centrifugal force on reducing castable section thickness is known. Additionally it should be noted that the centrifugal force also assists in reducing trapped air and thus improves porosity.

For study 03, the ANOVA analysis shows that by far the most important parameter that gives the highest contribution to surface finish is the feedrate (96%). Within the range of values used in this study, it can be said that all other factors tested do not seem to contribute very significantly to the surface quality. Similarly the interactions assumed seem not to give significant effect and thus can be said to be non-existent. It is therefore a reasonable practice to first select a suitable feedrate and then adjust the depth of cut and cutting speed. Although the effects of depth of cut and coolant are not very strong, the ANOVA results suggest that improved surface finish can further be ensured by selecting a higher depth of cut (1 mm as opposed to 0.4 mm) and by employing coolant during machining. For a soft metal like pewter, the depth of cut should not be too small or the fine chips will get adhered to the workpiece more easily.

4.0 CONCLUSION

Within the range of values tested in this study, the following conclusions can be made :

- The cooling rate gives the highest contribution to the shrinkage of pewter casting, this is followed by the pouring temperature.
- Copper content in pewter gives the highest contribution to the hardness of the alloy. This is followed by the cooling rate.
- The feedrate contributes most to the surface finish of turned pewter product.

References

1. Roy, Ranjit K., A Primer on The Taguchi Method, New York : Van Nostrand Reinhold, 1990.
2. Tan, Thean Chan , Pewter Manufacturing Process, B. Eng Thesis, Universiti Teknologi Malaysia, 1998.