Viability of casting a bearing bronze using a permanent mould for a small foundry

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Abstract – Many small foundry operators find themselves unable to deal adequately with output quality for various reasons. Often lack of capital required for investment in skills and equipment is given as a major setback. The work in this research sought to address one element of usage of a permanent mould for casting bearing quality bronze as opposed to commonly practiced sand moulding. In addition a check on key composition factors as well as their impact on typical bearing properties were evaluated for some test castings.

Index Terms - Bearing quality, permanent mould, sand casting, microstructure, hardness and friction

1. INTRODUCTION

BEARING quality bronze castings are produced by sand moulding by a number of small scale foundries in Zambia. The sector seeks to take advantage of readily available copper cathode as well as bronze scrap and add value for the local market. This supports the economy in terms of jobs and wealth creation as is also noted by Kader et al (2009). In 2012, total value addition based on copper was US$65million according to Ministry of Commerce, Trade and Industry of Zambia (2012). The contribution by bronze casting is very small as the bulk of that income comes from the wire and cable producer, Zamefa, for the non-ferrous metal sector. Part of the reason for low contribution by the bronze casters is that output quality of products is below most acceptable standards. One way to improve output quality is by use of permanent moulds for producing sleeve bearings.

A mould was conceived, designed and cast in grey cast iron based on a typical bronze bearing product. An additional but much smaller mould was also produced for laboratory use. More than forty test castings were done using the two moulds. A programme called MAGMASOFT was used to optimize the cast iron mould design, a subject dealt with extensively by Iqbal et al (2012). Factors considered for optimization in MAGMASOFT were metal flow, temperature distribution, cast modulus and occurrence of porosity.

2. METHODOLOGY

Test castings were produced using the moulds shown in Figures 2.1 and 2.2. Casting temperature, composition, volume or weight of casting and method of feeding were the parameters investigated.

MAGMASOFT was used to model the solidification and stress profile of the bearing bronze within the permanent mould cavity as casting takes place. Secondly, the permanent mould design itself was finalised using SolidWorks and was subjected to the above analysis to ascertain feasibility of its production. MAGMASOFT was also used to simulate both the design and the casting processes of both the mould and sleeve bearing in order to detect potential errors in the solidification and stress profiles. Simulation of design and casting are at present considered an integral part of computer aided engineering (CAE). There are several such systems in use today as discussed in detail by Darwish and Tamimi (1996).

Fig. 2.1: Cast iron mould at Heroes Foundry, Lusaka

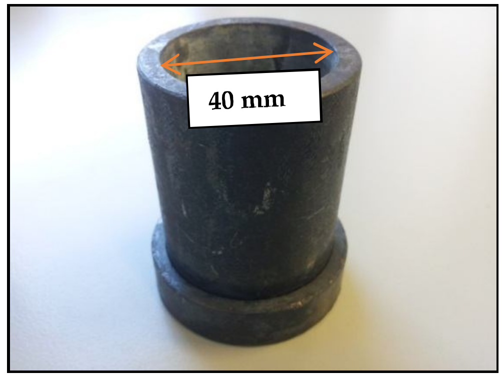

Fig. 2.2: Steel mould

Samples from test castings were subjected to chemical analysis using atomic absorption spectrometry (AAS). Other tests were Vickers hardness and dry friction using the ball on pin procedure.

3. RESULTS

Summary results are presented for chemical composition, hardness tests, metallography and friction of the bronze samples.

3.1 Chemical composition

Some statistical indicators for composition elements; copper (Cu), tin (Sn), lead (Pb) and nickel (Ni) are presented in Table 3.1a. Properties of a typical standard bearing bronze of known composition, C93200, are compared with the mean values obtained from the various samples tested. There was dilution of copper in the cast samples as seen from Table 3.1a. The compositions of tin and nickel were both close to the required standard composition of C93200. Lead was above the expected standard composition possibly due to the accumulation effect.

3.2 Hardness and dry sliding friction

Summary values for Vickers hardness (*Hv*) and coefficient of friction (μ) for the cast bronze samples tested are given in Table 3.2a. Both mean values for hardness and friction were above those expected for the standard C93200 alloy. Chill cast materials are expected to yield higher hardnesses than those cast in sand if all other conditions remained the same. Both hardness and friction values varied significantly from that of the standard C93200.

Increased tin content in the cast samples showed positive correlations coefficients, R, with both hardness and friction at R=0.77 and 0.30 respectively in figures 3.2a and 3.2b though below the threshold of 0.9 to suggest significant relationships. Nickel showed a similar trend with tin for hardness though with a lower R at 0.44 and showed the opposite effect with friction at R= -0.22.

Lead in both cases showed negative correlations with both hardness and friction in figures 3.2e and 3.2f at values of R = -0.36 and -0.48 respectively. The behaviour of lead with respect to the two properties is what would ordinarily be expected in the materials.

Table 3.1a: Chemical composition summary

	Cu	Sn	Pb	Ni
Minimum	68.5	2.7	1.2	0.2
1st Quartile	75.1	6.2	1.7	0.4
Median	77.4	10.0	2.9	0.8
4th Quartile	82.0	11.3	6.5	1.4
Maximum	92.9	17.6	12.1	2.5
Mean	80.1	9.0	4.1	1.4
Std. Deviation	5.4	3.4	2.6	1.3
C93200 alloy	87.0	11.0	1.00	1.00

Table 3.2a: Hardness and dry friction

	Hv	µ
Minimum	64.1	0.2
1st Quartile	100.1	0.2
Median	122.4	0.3
4th Quartile	153.2	0.3
Maximum	277.9	0.4
Mean	127.8	0.2
Std. Deviation	43.3	0.0
C93200 alloy	85.0	0.12

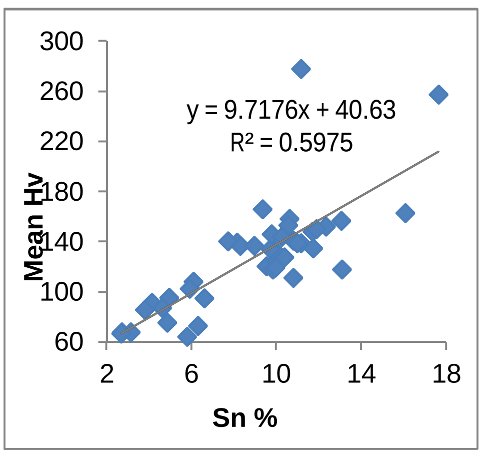

Fig.3.2a: Impact of tin on hardness

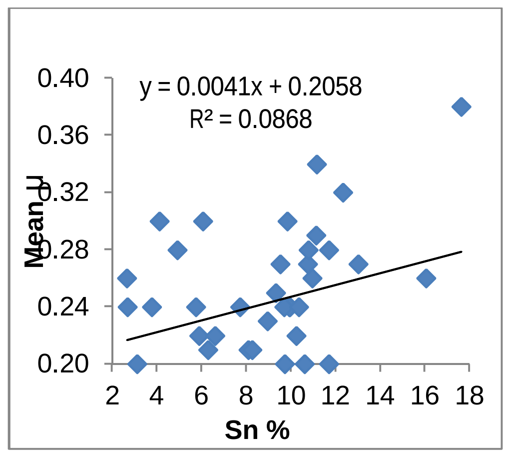

Fig.3.2b: Impact of tin content on friction

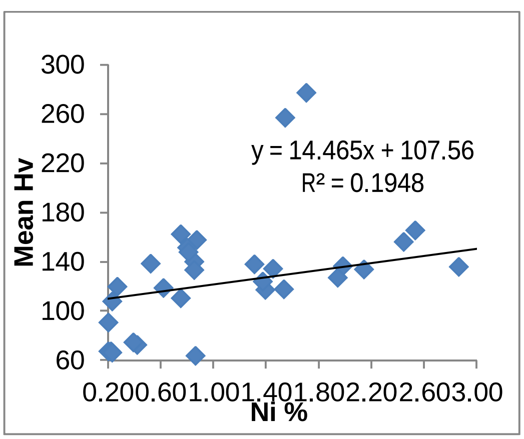

Fig.3.2c: Impact of nickel on hardness

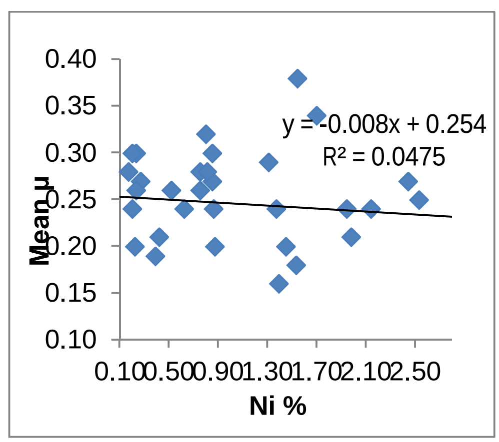

Fig.3.2d: Impact of nickel on friction

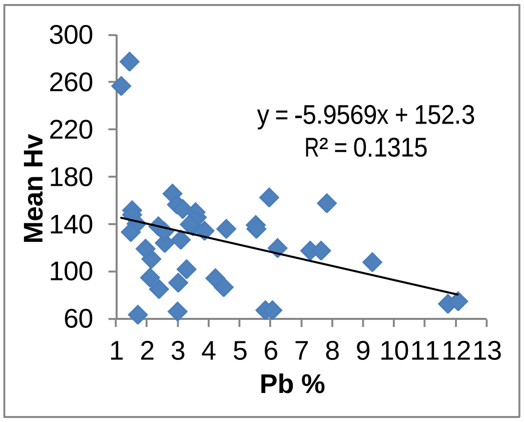

Fig.3.2e: Impact of lead on hardness

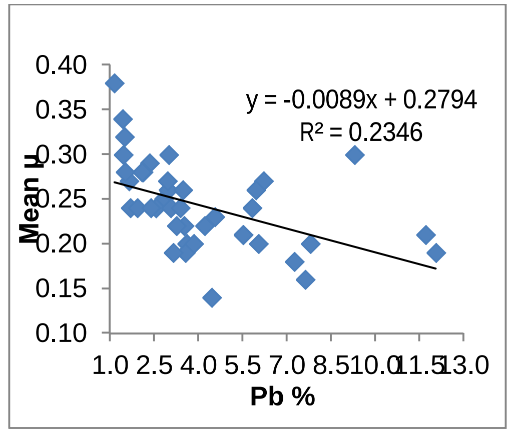

Fig.3.2f: Impact of lead on friction

3.3 Micro and macrostructures of the cast bronze samples

Microstructural analysis was carried out on some collected samples. Micrographs for some laboratory cast bronzes are shown in figures 3.3a and 3.3b. In addition micrographs for some sand cast bronze samples collected from foundries are shown in figures 3.3d and 3.3e. Permanent mould cast bronze materials showed consistency in solid solution alpha microstructure and were pore free compared with those that were sand cast at foundries on the Copper belt of Zambia. Better control of cast microstructure than is currently possible at foundry level can be achieved as was demonstrated with the laboratory castings.

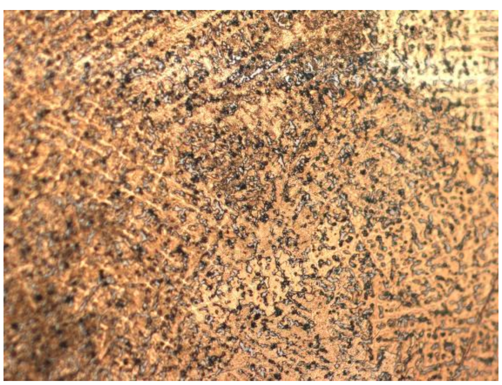

Fig.3.3a: Cast bronze 200X (WAX, UJ)

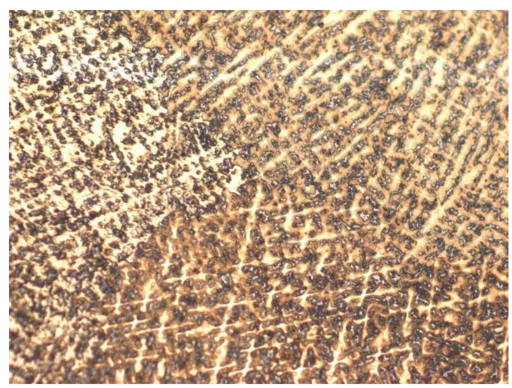

Fig.3.3b: Cast bronze 200X (WBA, UJ)

Figures 3.3e and 3.3f show a rough test casting using the permanent mould in figure 2.1. The objective of getting a near net finish casting was demonstrated but required a lot of improvements in a number of areas. Improvements in feeding of molten metal to the mould as well as its cooling within the mould. Incomplete fusion, cracks and cavities resulted from inadequate feeding and poor cooling on the mould. Figures 3.3g and 3.3h show the smaller castings using the mould in figure 2.2. Surface and internal finish of the castings in figures 3.3g and 3.3h were a lot better than those cast using the larger mould in figure 2.1. The differences in the two cases may be attributed to characteristics in molten metal feeding.

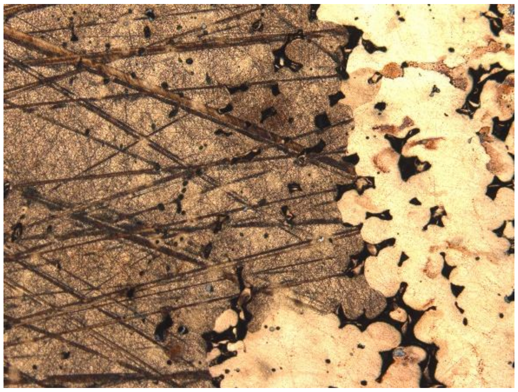

Fig.3.3c: Machining stock 50X (FFA, Fox)

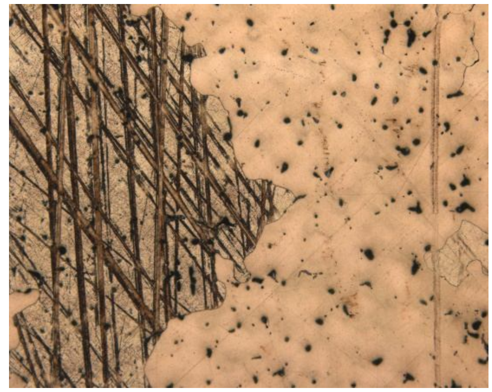

Fig.3.3d: Impeller scrap 50X (FFN, Fox)

Fig.3.3e: Cast sleeve using mould in fig.2.1

Fig.3.3f: Section through cast HFC

Fig.3.3g: Castings using mould in Fig. 2.2

Fig.3.3h: Sections through casting WAC

3.4 Magmasoft simulations

The permanent mould in figure 2.1 was recreated in a CAD software after which a simulation by MAGMASOFT was used to check temperature and casting modulus distribution among others during casting of the bronze sleeves as indicated in figures 3.4a and 3.4b. The best mode of feeding was through the bottom and the temperature distribution was such that the hottest metal remained at the sprue exit and maintaining favourable directional solidification throughout. The modulus during metal pouring as illustrated in Fig.3.4b showed a favourable feeding pattern. Although feeding from the bottom via the sprue was entirely by gravity without the need for pressure, there was complete mould filling.

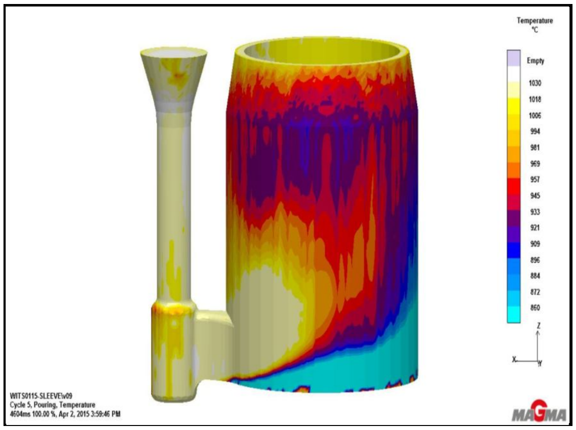

Fig.3.4a: Temp. distribution during pouring

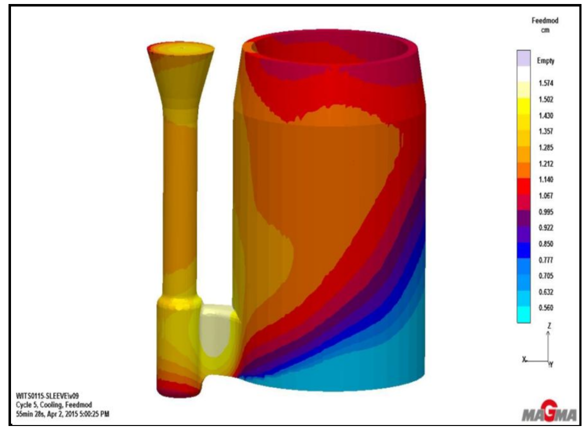

Fig.3.4b: Modulus distribution during pouring

3. DISCUSSION

More than forty test samples were cast at a foundry and laboratory. Tests possible on the samples were limited owing to sample dimensions or size but were considered adequate for small foundry application purposes. These were chemical analysis, hardness determinations, microstructural analysis and dry friction. Molten metal feeding in this case was only by direct gravity pour although in the simulation it was shown that feeding from the bottom via a sprue would have been more ideal.

Additions of controlled amounts of tin, lead and nickel to scrap bronze during melting showed that the key properties of the resulting casting could be significantly influenced as seen in figures 3.2a, 3.2c and 3.2e. That would make it possible for small foundry operators to develop a system of ensuring that composition of the melt is right and give a better chance for attaining the ideal microstructure right at the start.

The relatively rapid cooling attained in permanent moulds as opposed to that likely in sand casting can lead to dense and pore free structures. Upadhyaya et al (1997) suggested that a dense microstructure had beneficial effects on wear and other mechanical properties. It has also been suggested that there was no clear correlation between a bearing's friction and other mechanical properties according to Yuanyuan et al (1996). Elimination of porosity in microstructures however can lead to good wear resistance as was possible in a number of the laboratory cast bronze in this work.

Without significant amounts of alloying elements present in the bronze, it would not be possible to attain a structure that precipitates vital second phase constituents. Presence of harder beta (β) or the more stable delta (δ) and gamma (γ) phases lead to better load bearing capacities than is possible in simple primary α structures.

Temperature distribution and modulus were such that directional solidification was encouraged during mould filling according to results of simulations in figures 3.4a and 3.4b. Highest molten metal temperatures coincided with source of metal giving an opportunity for uninterrupted feeding. High feed modulus ratios above unity (1) on the other hand were in areas in a position to provide feed metal to the casting in lower regions.

4. CONCLUSIONS

4.1 Chemical analysis results of the cast samples tested showed that it was possible to control small foundry output and meet acceptable composition specifications. Although variation was wide with respect to all the elements in the cast bronze bearings tested, copper showed the highest

4.2 Measured hardness and friction values for the cast samples were higher than respective mean values for the standard C93200. This may be attributed to the chilling effect of permanent mould casting.

4.3 The impacts of tin, lead and nickel on mechanical properties showed that it was possible to influence them. Each of the major alloying elements can be used to control key properties in a casting even at a small foundry level.

4.4 Chill casting using a permanent mould encourages evolution of finer and denser microstructures that ultimately impact positively on key properties of the bearing.

4.5 Application of simulation techniques prior to production of the permanent mould and bearings from it improves overall design while cutting costs and enhances understanding of metal flow behaviour during actual casting conditions.

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