A Review of Casting Quality Problems and Potential Solutions in Small Scale Foundries

Lungu C and Paterson A E

Abstract — In this research hypothesis paper, a review of challenges encountered during production of castings in small scale under-resourced foundries is presented. Small scale enterprises form the core of economies in many countries. However, castings produced in these foundries have poor microstructure with unacceptable porosity in general. Important bearing properties of friction and wear resistance are dependant on a good microstructure. Results from testing randomly obtained cast bearing samples showed irregular microstructure, poor mechanical properties and high porosity.

Index Terms— Sustainable, quality castings, bronze sleeve bearings, design of process, microstructure, mechanical properties.

1 Introduction

THIS paper reviews the challenges encountered in producing bronze sleeve bearings successfully in small scale foundries (SSFs) in general. Sleeve bearings, as opposed to rolling element bearings, are commonly used in industrial equipment in open cast mining and mineral processing equipment. This paper was motivated by a research hypothesis that reliable short run production of commercial quality bearings is sustainably achievable in small foundries in Zambia at a cost that represents value for money.The paper therefore explores common casting quality problems encountered in small foundry facilities and possible solutions that may be applied to address them.

Fig. 1.1: Scrap flange sleeve bearing used as raw material at Fox Foundry, Kitwe (February, 2014)

2 Literature Review

2.1 Quality bearings are castable in small scale foundries

Key variables such as composition, orientation of casting, mode of molten metal pouring and the rate of cooling impact greatly on the product microstructure as in [1], [2]. Employing counter gravity feeding of castings for example makes it possible to deliver molten metal under laminar conditions and avoids creation of bi-films [2]. Bi-films are known to be sources of many types of defects in castings such as porosity and cracks.

Getting casting parameters right and maintaining them through out the casting process is critical to optimum product microstructure and mechanical properties. SSFs face operational difficulties in setting and monitoring casting quality parameters throughout the process. Charge and melt compositions are important to measure regularly just as process temperature is. It was observed at one foundry in Kitwe, Zambia that temperature for example was only determined prior to charging to the furnace. Temperature of the molten metal itself was not measured at the Kitwe foundry. Installing and maintaining reliable equipment for quality control is expensive. In addition to quality control equipment is the issue of documenting operational procedures which require highly skilled personnel to write and implement.

Fig.2.1: Melting of bronze in progress at Fox Foundry, Kitwe (February, 2014)

Although there are a handful of material combinations for bearing applications as in [3], the use of copper base alloyed with tin and nickel is widespread. By its nature bronze is a semi precious material and is expensive and because of its high monetary value, security of materials and operational cash flow are a concern for the SSF.

One possibile way of overcoming material security and cash flow problems is getting production facilities for an SSF bronze producer located in a major consumer's premises. That would also be referred to as a toll treatment arrangement. Bearing manufacture by

the toll treatment route described above is a form of partnering with major equipment suppliers or users and is also referred to in section 2.2 below. Lead as an alloying element has a dual role in bearings; it acts as a lubricant and aids machining during finishing operations. The amount of lead added to bronze alloys depends upon application of the bearing and the level of machining required after casting. Typical amounts are from 1 to 3% but can be higher for high load - slow speed bearing applications.

However, in recent years there has been a trend to eliminate the use of lead in bronze bearings and other copper alloys in general and substitute it with bismuth for environmental reasons [4]. The management of bismuth use however would be more difficult than that of lead despite the environmental benefits that are possible from lead substitution according to [4]. The environmental benefits of lead substitution should therefore be weighed against foundry control mechanisms possible for bismuth especially for a small foundry set up.

Fig.2.2: Mould prepared for a secondary crusher countershaft bearing billet at Fox Foundry (February, 2014)

On the other hand lubrication properties for bismuth are known to be lower than those of lead and it tends to alloy with other bearing constituents such as tin forming entirely new phases and introducing new parameters to deal with. Final properties of bearings would require even stricter control under poorly resourced SSF conditions to ensure good performance. Bismuth tends to expand more than lead does at all treatment temperatures and can therefore lead to distortions in the final castings.

2.2 Good attributes of small businesses

There is ample evidence that a cocktail of key success factors exist for long term survival of small businesses as stated in [5], [6], [7]. Individual businesses on their own find it difficult to deal effectively with the aspect of production cost in a local context for example [6]. The local market for SSF output must generate value for money for the producer to remain relevant in their market sector. Other than production cost, the value equation includes delivery and performance reliability of castings as well as production time savings being part of the major considerations.

The role played by central or local government in supporting small businesses in terms of both soft and hard infrastructure was also critical as elaborated in [7]. Timely government intervention in the right areas and at the right times were known to greatly boost the performance of the SSF.

A factor often ignored but which should be embraced by many small businesses is that of association or partnership with a principal original equipment manufacturer (OEM) as explained by [8]. A linkage between an SSF and OEM is beneficial in many ways and helps to diffuse and transfer technology to the former entity where a status of certified local supplier is attained.

Transformation planning and implementation in the face of external shocks was more likely to succeed in small businesses than it would in their larger counterparts as concluded by [7]. The model used in [7] involved subjecting collected data to multiple regression analysis. Factors such as firm size, age of firm, skilled workers and export sales strongly influenced success on their own as individual factors and acting together as collective factors. Small businesses can adopt and use positive change management as described in transformation planning to improve on their performance and gain competitiveness.

2.3 Design and implementation of production

A number of researchers have delved into the issue of the use of expert systems (algorithms and proprietary software) to optimize materials selection and production [9], [10], [11], [12]. In some cases potential suppliers of input materials to the production process are considered to be part of the equation. Process optimisation eliminates costly trial and error techniques.

The software referred to above comes in many forms such as Computer Aided Casting Process Selection (CACPS) and Materials Process Advisor (MPA) to mention only but two. The Fuzzy Logic approach has also been used [10], [11] in arriving at the appropriate choice of materials and the production process particularly in situations where primary input data is subjective or imprecise. Proprietary software is ordinarily expensive and out of reach of small foundries. It must be stated that small foundries can make use of open source versions of optimization software when available.

Although fairly old now, the Taguchi method of production design (or design of experiment where appropriate) using orthogonal arrays is referred to by many authors [13]. The first step involves careful and prior analysis of the independent (input factors or x_s) and dependent variables (output factors, responses or y_s) involved in a given situation. The levels of each factor to be tested will then be assigned and that would then help determine the total number of experiments, n, to be conducted in one trial run and that is denoted as L_n. The number of experiments actually required to optimize parameters in the Taguchi approach is many times lower than that would be possible in a conventional factorial design of the form p^k, where p is the number of levels to vary each x factor and k the total number of x factors considered.

The Taguchi approach and other production or experiment optimization techniques once applied diligently can result in significant savings in process costs for small foundries. From the foregoing, it is important even for the least resourced SSF to apply some form of process optimization that is easy to understand and use. Optimization ultimately saves time and a lot of resources for that matter and

gives higher reliabilities for product performance.

3 Conclusions

3.1 Bronze sleeve bearings can be successfully produced in an under-resourced small scale foundry just as they are in larger and better equipped foundries providing parameters that impact on final cast microstructure are optimised. Optimization can be achieved by application of one of several techniques available commercially or just adapted to suit a specific foundry environment.

3.2 Some of the important parameters to consider are cast temperature, melt composition, duration of pouring, weight of casting, rate of cooling and mode of feeding. These factors individually or in combination affect the cast microstructure and consequently all other secondary cast properties.

3.3 A working partnership between a small foundry bronze producer and a major consumer through a tolling arrangement eliminates unnecessary costs and improves security of process materials for the business and improves competitiveness.

3.4 Although lead remains the best alloying element in bronzes for lubrication and machining purposes consideration should be given for its substitution with bismuth where that is possible. However whenever lead, it should be kept to the bearest required minimum.

3.5 Government role at all levels in terms of provision of both hard and soft infrastructure is critical for the performance of the small scale foundry bronze producer. Small businesses are also quicker and more successful in adapting to change than their larger counterparts.

3.6 The Taguchi approach on DOE remains the best option among others even for the SSF set-up. It optimizes the use of resources and places control of production parameters only on those that have the greatest impact on the desired outcome.

Acknowledgment

The authors wish to thank the University of Zambia programme of Strengthening of Teaching Research and Consultancy Capacity (STRECC) for financial support. The University of the Witwatersrand for providing facilities and research advice during the course of work.

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- *Chozi Lungu is currently pursuing a doctor of philosophy programme in casting of bronze sleeve bearings at the School of Chemical and Metallurgical Engineering, University of Witwatersrand, South Africa, PH-+27736334815. E-mail: chozi.lungu"students.wits.ac.za*
- *Dr Tony Paterson is currently a senior Lecturer at the School of Chemical and Metallurgical Engineering,University of Witwatersrand in South Africa, PH-+27826024517. E-mail: tony.paterson@wits.ac.za*