SAND SINTERING PROBLEM ON BRONZE CASTINGS

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ABSTRACT

A research has been carried out on surface defects of castings. The problem of sand sintering on castings of ferrous and non ferrous metals is a well known surface defect, which may lead to poor quality product and a huge economic loss for finishing and cleaning. The problem occurs on a 32 kg closed type tin bronze impellers used for water works. The objective of this paper is to analyze the causes of the surface defect and develop the methods of sand sintering protection on the tin bronze impeller body and internal surfaces. The research method used includes green sand molding, data analysis, physical observation, photographic analysis, grinding and fish bone diagram. The causes, effects and remedial actions required to improve the quality of casting with regard to impeller is presented in this paper. By using the remedial methods applied to prediction time of the impeller reduced to about 35minutes to 1 hr and the total cost for finishing total impellers exposed to sand sintering reduced to 15-20 USD.

Key words: *Sand casting, Sand sintering, Impeller, Burn on, Bentonite*.

INTRODUCTION

As practice and literature show the ideal mold would possess a smooth, impervious surface capable of being faithfully reproduced on the casting of both ferrous and non-ferrous metals [1,2]. At higher temperature surface roughness and sand adhesion can be encountered with loss of appearance and increased dressing costs. In some cases the molding material becomes infused with metal to form a solid mass, which may be difficult to remove and especially if the condition occurs in a confined pocket the casting itself may be scrapped. Literatures show that one of the reasons for surface roughness or sand sintering is burn on [1-4]. Burn on (sintering) is a strongly adhered layer of mold materials on the surface of castings. This happens when the mold material is reacting with the liquid metal while pouring. Thickness of the layer may reach from 3-4mm and some times more, which when it is more than 4mm it may be said to be void or pore [4]. This time improvements have made to control the formation of burn on, however all the processes related with the formation of burn on have not yet identified and there is no universal recommendation on the causes of formation and protection of it [4, 5]. Based on the adhering characteristics of sand grain with molding sand mix and core mix, burn on can be divided in to chemical, mechanical and thermal. Mechanical adhering is a type in which the layer of mold or core is penetrated or impregnated with the grain of the metal [1-3].

While in chemical type of burn on sand grain is interacted with reaction products of metal and mold materials. The thermal burn on is formed without the direct participation of metal. In this case the grain of sand is interacted with single mass of the low melting point included materials, which are formed as a result of mold material components reaction. Sand that contain low melting point materials are always associated with thermal type burn on. Often thermal burn on is formed on the layers of chemical and mechanical burn on. Classification of burn on in to mechanical and chemical burn on up to some degree is conditional. At the boarder of metal mold (at the interface) chemical reaction is formed first, which products are facilitating penetration of metal in the form of cavity (pore) [2, 3].

Burn on is one of the widely distributed surface defect of castings. Based on statistical data analysis about 12-15% of assigned production time is lost on burn on removal. Burn on that is difficult to remove is formed when metal or product of reaction penetrates the mold in depth greater than the quartz sand grain in diameter [4]. If the depth is less than the diameter of the quartz sand, burn on can be removed easily leaving marks of sand grains on the surface of castings. Number of marks on the surface of castings determines the roughness of the cast. In some countries these marks are not categorized as defects. In some countries degree of roughness of the cast surface is determined by special method such as using surface roughness measuring instrument.

It has been mentioned in many research works that metal penetrate in the form of porosity is in

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the liquid condition, i.e. from the moment of pouring to the formation of solid layer. In recent years a popular hypothesis on the formation of mechanical burn on is considered to be the presence of vapor (steam) forming metals in the charge [2, 4].

Both metal and mold factors are involved in the process and penetration into voids in the molding material depends primarily upon the pressure head of liquid and thus upon the design, orientation and feeding technique associated with a particular casting.

Coating may reduce the problems mentioned above. According to Xingye [13], casting coating coated in the mold cavity or mold surface, improve its surface refractoriness, chemical stability, and resistance to erosion of sand. Foundry coatings and surface quality of the casting are closely related. Coating reduces the casting surface adhering sand and chemical bonded sand. Coatings also reduce the casting surface of the sand and the sand flushing. In the process of casting, high temperature liquid metal on the casting mold and core surface has strong thermal radiation effects. Mold and core heat produced by the thermal stress and thermal wet tensile strength will lead to the cause of casting sand sintering [6, 13]. Foundry coatings can reduce the mold or core of the radiation heating, thereby reducing or eliminating the sand inclusion defects. Coating also can penetrate into the mold and core sand between surface, there by strengthening the mold or core surface strength and anti scour ability (rub), reduce casting defects of sand flushing. Coatings also improve performance and internal quality of casting surface. In the process, casting coating is done by adding insulation material and chill material, so as to improve the mold cavity temperature distribution and control of solidification and crystallization process of casting surface, thereby reducing the cold cracking and heat crack [13].

Mold and core has a lot of pores, in casting and solidification with static and dynamic pressure of liquid metal infiltration pore formation, adhesion on the casting surface is difficult to clean the metal shell, called “mechanical sand”[3, 4, 6, 13]. Application of foundry coating can be put on mold and core sand surface layer between the liquid metal and infiltration jam pore, the channel, reduce the casting penetration. The liquid bronze in the casting at lower temperature, the surface will continue to generate metal oxide, consequently the metal oxide and silica sand chemical reactions occurs, resulting in the “chemical bonded sand casting surface”[3, 6, 13]. The use of foundry coating can make the liquid metal and mold or core surface to inhibit their isolation, chemical reaction between, reduce or eliminate the casting surface chemical sand [13]. The quality of casting as mentioned in the work of Tegegn et la, [6] can be assessed by using quality control instruments such as statistical quality control method. Various quality analysis methods that include Ishikawa diagram, Pareto diagram, control chart, etc, are essential in different conditions. Causes in the fish bone diagram are often categorized, such as to the 6 M's. Cause-and-effect diagrams can reveal key relationships among various variables, and the possible causes provide additional insight into process behavior. The six M’s (used in manufacturing industry: Machine (technology), Method (process), Material (Includes Raw Material, Consumables and Information.), [7, 8]. Man Power (physical work)/Mind Power (brain work), Measurement (Inspection) Milieu/Mother Nature (Environment). Fishbone diagram is commonly used to analyze human, machine, material and method factors of production [8]. The Fishbone diagram (also called the Ishikawa diagram) is a tool for identifying the root causes of quality problems. It is used when there are many possible causes of problems, especially when the traditional method of quality assurance is difficult, and when it is necessary to analyze root causes of the problem [6, 12]. Thus the quality problem of impeller has been analyzed using fish bone diagram.

In the case one of the foundry industry of one melt (500kg metal) a total of 10 pieces of bronze impeller casts have been produced. Of the 10 impellers 3 are rejected due to various metallurgical and technological problems and 7 casts are exposed to sand sintering (adhering).To clean the burn on the surface of the metal at least 3 grinding discs and 2-3 hours working time for a single impeller is required. Chiseling work is also done for internal part of the product mentioned above. From the information of production head and production cost data (Table 2) of the industry a total of about 80 USD per melt is estimated and about 17.7 working hours is assigned for surface finishing only. This implies that there is a big economic loss and calls for corrective measures to be taken on time.

Based on the above information from literatures and practical cases, it is clear that sand adhering defect or sand sintering(burn on) is a function of many variables and has a negative economic impact .Thus analyzing the specific cause or causes of sand sintering (sand adhering) is vital to improve the quality of impeller used for water works.

METHODS AND MATERIALS

Materials

To carry out the research samples of closed impeller cast from tin bronze with the compositions given in table 1 have been taken for analysis. The net weight of one impeller is 32 kg with internal intricate shape of very small thickness blades. The alloy was prepared in the non ferrous metal foundry section using the available yellow brass scraps by adding pure copper, pure tin for material composition balance that will give the required property in service and certain amount of zinc for compensation of its lost amount due to volatilization in melting. Composition analysis is done using TRECN portable solid spectroscopy of 4 mm minimum sample thickness handling type and has been made for the purpose of determining low melting metals present in this particular material, which in some cases are causes of sand sintering.

Green sand mainly bonded with bentonite clay was used for mold making. Based on the data obtained from production department of the industry and current experience, 255 kg green sand, about 25 kg clay, and 58.8 kg metal is used for single impeller casting.

Table1; composition of tin bronze used for impeller production

Element	%
Zn	13
Pb	1.76
Sn	7.27
P	0.012
Fe	0.413
Ni	0.158
Cu	77.1
Others*	0.321

*including trace elements like Si, Mn, Mg, Te, As, Sb, Cd, Bi, Ag, Co, Al, S, and Be.

Methods of Research

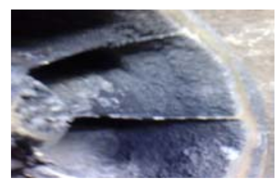
The analysis was supported by brain-storming sessions with operators, production heads, and marketing experts of the industry in order to obtain detailed feedback on the problem, and physical observation in order to verify the existing problem. Furthermore, assessment of the degree of the damage due to sand adhering problem and to establish the appropriate method of prevention, industrial data analysis particularly material cost, operation cost and working hours lost for finishing have been carried out.

Photograph of the products were used for analysis. In figure 1 the photographs of impeller are displayed. The disc type impeller has different dimensions among, which the major diameter is 391 mm and the minor diameter is 260mm at the top and86 mm at the bottom, the total height is 123 mm. The internal part is hollow and intricate helical shape with about 5mm thickness bladed channel.

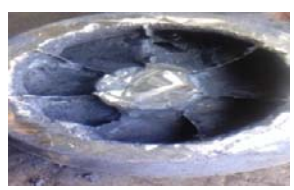
Surface finishing has been made by grinding and machining. Grinding also helps to identify the type of sand adhering and degree of adherence.

Fishbone diagram was used for cause and effect analysis

a. Immediately after shakeout from the mold



b. First hand grinding



c. After grinding the surface

d. After outer grinding both surfaces

e .Finished work piece

Figure 1 Photographs of impellers samples selected for analysis

Table 2 shows the required manpower, equipment and process cost. Part of the data has been gathered from the Production Department of the plant in addition to the data from Purchasing Department. The whole data refers to the finishing requirements for one impeller. As has been mentioned earlier, about 7 impellers were exposed to sand sintering problem and the total finishing cost in birr was Birr 1626.17, which was equivalent to around 80 USD.

Table 2: Requirements for finishing one impeller [factory Data]

No.	Operation	Tool/device	Quantity	Cost in Birr	Labor	Time, hrs.	Labor cost, Birr
1	Shaking out	Hammer	2 pieces	---	2	0.5	5.41
2	Knocking	Hammerer and brush	2 pieces each	-----	2	0.5	5.41
3	Cutting	Cutting disc	3 pieces	55.00 for one piece	1	0.5	2.7
4	Grinding	Grinding disc	1 piece	35.00 Birr	2	4:00	43.28
5	Chiseling and scraping	Chisels, scrapers	2 pieces	-----	2	3:00	32.46
6	Machining	Lathe machine	1 piece	----	1	9:00	48.69
7	Polishing	Sand paper	-----	1.66 /piece	1	0.5	2.7
	Subtotal			91.66 Birr			140.65
	Grand total			232.31 Birr			

Tools, machines and devices used

For the process of casting an induction furnace capacity of 500 Kg for melting, Lip ladle capacity of also 500 Kg for pouring the metal in to the mold, Molding flasks for molding, Beam balance for charge weight measurement, vernier calipers for measuring the impeller dimensions, crane for carrying the ladle were used.

RESULT AND DISCUSSION

The photographs in Fig. 1 show that sand sintering has strongly affected the surface finish of the cast including the internal corners, edges and holes of the impeller produced. The procedure of sand sintering removal also needs various consecutive steps, which include shaking out, knocking, cutting, grinding, chiseling and scraping, machining and polishing (Table 2). The photographs depict only grinding operation. The process requires time, tools, metal loss and labor as a result of which huge finance is required. As seen in Fig. 1(d) even after the 4^{th} steps of finishing work the internal surface of the impeller remains with full adhered(sintered) sands, which requires further work, probably chisel work and scrapping, which may also affect the surface quality due to scratching. Though the adhered sand has been removed on the surface of the cast (Fig. 1 (e)), there remain rough surface finish and sand traces, which indicate the negative impact of sand adhering on the surface quality of castings. This calls for the need for polishing. As has been discussed the impeller has been produced from copper alloys (Table 1). At this point analyzing the formation of sintering in terms of alloy properties is necessary.

According to ASM Handbook [10] copper alloys are poured into many types of castings such as sand, shell, investment, permanent mold, chemical sand, centrifugal, and die. Group I alloys are alloys that have a narrow freezing range, that is, a range of 50 °C between the liquidus and solidus. Group II alloys are those that have an intermediate freezing range, that is, a freezing range of 50 to 110 °C between the liquidus and the solidus. Group III alloys have a wide freezing range. These alloys have a freezing range of well over 110 °C even up to 170 °C [10, 11].

From Table 1 the material composition shows that the bronze type is grouped under group III [10] of copper alloys, which are the wide freezing range (pouring temperature from 1150^oC to 1260^oC) groups. The material obtained in Table 1 has been developed in the foundry shop and spectroscopic composition analysis confirmed that this alloy is similar to group III Tin bronze alloys with approximate content of 8% Tin. These groups of alloys are mostly suitable for water works including pumps, pipes, taps and impellers .It is because they resist corrosion and impingent effect of water. They have also good cast ability and relatively low solidification shrinkage. That is why they are selected for casting of impellers. However, since low melting point alloys are constituents of this particular alloy, the possibility of steam and vapor formation that can strongly facilitate the formation of sand sintering due to reaction with mold materials products highly expected.

From observation, practical experience of the factory and brain storming of operators, it has been found that in the foundry shop, where the impellers are produced temperature control of melting has not been done properly. Because of this the pouring temperature in most cases reach up to 1280 ^{o}C-1300 ^{o}C and above, which is above the normal range that ultimately led sand expansion as a result of which sand sintering, has been formed on the surface of the cast. It has been understood that green silica sand with hand ramming technique has been used for molding.

Since green sand contains moisture, there can be formation of vapor and steam and reaction with low melting metal products which is considered as one cause of sand sintering formation. Hand ramming also causes soft mold as a result of which mold erosion occurs as one factory sand sintering. The bentonite clay type has been used for molding. However, it was not clear whether the clay type is calcium bentonite or sodium bentonite. Calcium bentonite clay has an ability to develop green properties quickly, has better flow ability through the sand system and in to tight pockets on patterns, lower deformation characteristics at the same moisture percentages as a result of which it will be easy to remove from the surface of the cast. It is also suited for low melting alloy castings. Sodium bentonite is commonly working in higher dry and elevated temperatures with high wet strength that is suitable for iron and steel melting. It should be bear in mind that common name for collective clays is bentonite but based on their composition they differ in property and specific application.

The green silica sand in addition to its comparatively low refractoriness may contain fine particles of sands, dead clays or other inclusions that can be fused in early time and react with the liquid metal may lead to sintering. Knowledge about fluid flow during the filling of castings is important not only in itself, but because it affects heat transfer both during and after filling [10]. It is because of this reason that more sintered sand remains on the surface of the cast at low temperature, while solidification takes place or sand sintering starts to form at high temperatures. In most cases the unpressurized gating system is used for nonferrous metal castings [9, 10]. But the gating system used in this foundry shop for pouring the molten tin bronze was pressurized top gating system, which may be the reason for turbulent flow and sand erosion. Top gating system is also mostly suspected for air entrapment.

From the observation and brainstorming of employees it has been understood that the riser type is a cylindrical in shape and the correct size fitted with the mass of the cast has not clearly identified. From data analysis it has been seen that the unknown size of the riser which was not match with the 32kg mass bronze impeller cause excess metal loss. The total mass of the waste metal from 1 impeller casting is 26Kg.This amount of metal is also affected by sand sintering and affects the remelting process causing large amount of dross and slag. Manual ramming was also used on molding process. Other technological and human factors such as skill gap, carelessness, management problem, knowledge gap among employees, temperature controlling problem, molding techniques are also considered as reasons of sand adhering on the impeller surface.

Analyzing the causes and effects using fish bone diagram may help to develop remedial actions to reduce sand sintering problem [12]. From Fig. 2, it is evident that sand sintering on bronze impeller casting surface is formed due to many reasons. If considering the pouring temperature range, the practice in this foundry shop, where impeller is produced is higher than the standard pouring temperature and this higher temperature may fuse sand particles, dusts will char, volatile materials evaporated out to the surface and deposited, the very low melting point metals (alloying elements of the given bronze) may react with all the impurities, due to this high temperature the softly rammed mold will be dried more than the need and get cracked out. This is because of the absence of temperature regulation as there is no device to control the pouring temperature. The metal is grouped as mentioned above under the long range freezing groups and thus the high temperature liquid metal remains in the mold for long time causing burn on of the sand mold and clay particles. The clay type or bentonite group as has been informed from the brain storming is not identified, but suggested that it is calcium bentonite type, which even though it has a good fluidity and distribution, it does not resist high temperature and cause disbonding of sand particles as a result of which erosion of mold occurs. From practice it has been found that coating or mold dressing was not commonly practiced at the beginning. Thus the mold may also be eroded due to the flow characteristics of the metal as the gating system is only top type that is commonly exposed to turbulence. At the same time the pouring mechanism was manual with lip type ladle, thus the uncontrolled filling of the mold leads to turbulence. The flow characteristics of liquid metal whether N_{Re} is greater than the critical (greater than 2000) [9, 10] or not, where Reynolds's number (*N*Re) is defined by:

$$N_{\mathrm{Re}} = \frac{VD_e}{\nu} \tag{1}$$

Where ν is the kinematic viscosity and *D*e is the equivalent diameter. According to N_{Re} value the flow may be laminar which does not affect the quality of casting or turbulent, which may lead to the formation of porosity, sand sintering (burn on) or other related surface defects. This number also determines the change in the cross section of a vertical sprue that will compensate for the acceleration of the molten metal as it drops through the sprue under the influence of gravity [10]. The height of pouring and time of pouring have not been properly adjusted. Especially pouring height varied with the wide range and lead to high pressure head that again influence on the flow characteristics of the liquid bronze and turbulence flow facilitates liquid metal and mold material reaction.

The impeller has sharp edged internal surfaces, where pressurized flow may lead to erosion of the core at the junction and sharp edges of the mold. It implies that the proper design of gating system plays a vital role on the surface quality of casting. As mentioned earlier sand sintering is a multi factor problem. From Fig. 2 it is clear that man power problem, equipment problem, gating technology problem materials related problem, methods utilized and metal property are the major factors for sand sintering to be formed. Taking these factors and their sub factors in to consideration, short term training, maintenance of equipment, mold material selection, proper mold ramming using machine molding methods have been practiced and improvement of the problem has been seen. Regarding gating system technology and fluid characteristics of metal(metal property in Fig. 2) the foundry factory (as obtained from brain storming of the head) has designed to upgrade the employees qualification using long term training and as clearly under stood, the long term training has been already started.

On the process of grinding the sand adhered surface, it has been understood that the sintered sand has been removed relatively easily except at the internal corners of the impeller, where additional work (chiseling and scrapping) was required. With ease removal of the sintered sand it has been confirmed that the type of adhering is chemical type, which has been formed due to the reaction of the metal products and mold materials.

However, trace of sand and scratches of the surface remained on the impeller surface, which needs additional polishing as the impeller has no suitable geometric shape for machining.

Though the sintered sand has been removed easily, the amount of grinding disc required for a single impeller and the time spent for cleaning incurs unintended financial costs and methods were devised to alleviate the problem.

The methods used to improve the sand sintering problem in the particular case were using dry sand mold, using green sand bonded with synthetic binders, dressing (coating) the mold surface using coal dust and graphite powders. From dressing, it has been understood that the graphite powder has shown better surface finish as it resists thermal effect, the mixing and ramming of sand has been changed in to machine ramming and appropriate ramming technique has been achieved. The pouring height was adjusted to be not more than 200 mm, where the turbulence flow and pressure has reduced to some extent. Pouring has been done using crane with relatively controlled conditions. Because of these, there appeared product quality improvements of the impeller, where low labor and less cost of finishing has been achieved. It has been reported from the head of production department that by using the remedial methods finishing time of the impeller reduced to about 35-60 minutes to 1 hour and the total cost for finishing total impellers exposed to sand sintering reduced to 15-20 USD.

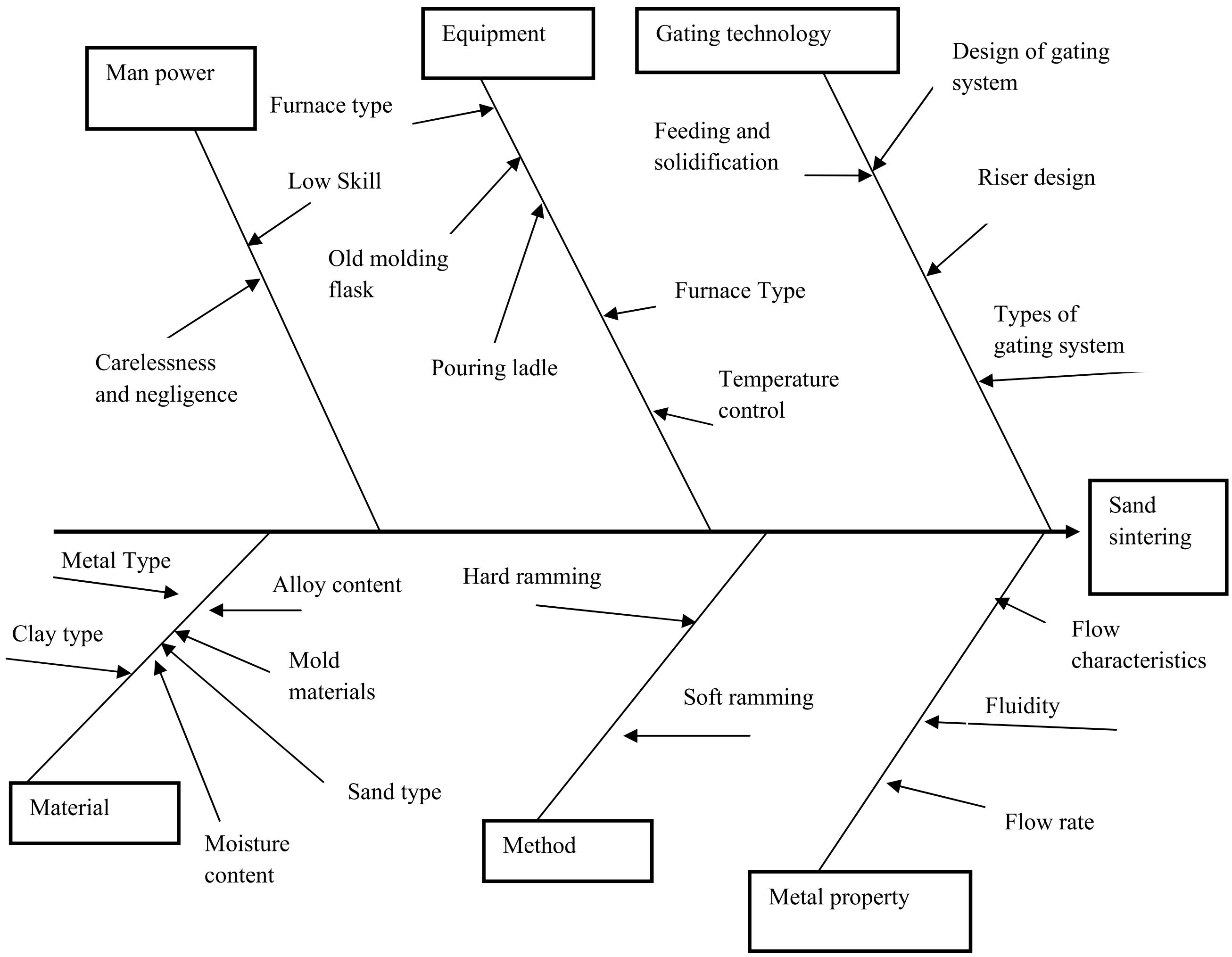


Figure 2 Cause and effect diagram of sand sintering on bronze casting impeller

CONCLUSION

From the literature, it is known that sand sintering is one of the well known surface defects of castings that need a lot of finance for its removal. Many researchers have suggested various remedial methods and have agreed that the major reasons for this problem are sand itself, high temperature and casting skill.

The main method of sand sintering removal is grinding, however after grinding machining and polishing are also considered for better surface finish and accuracy. It is understood that sand sintering is multi factors problem that requires detailed study of its nature. From the analysis result, the sintered sand type is chemical type, which is the result of mold materials and liquid metals reaction that can be controlled using different techniques including pouring temperature regulation and proper mold dressing. It is thus possible to conclude that for the formation of chemical type sand sintering, the causes mentioned in the study are critical factors with possibilities of improvements and some already improved.

The methods used to reduce the sand sintering minimized but not completely eliminated the problem. The methods of improvements (dry sand molding, resin binder application, machine molding, dressing, painting the mold using refectories, and graphite) have been tested and approved for this particular alloy (Table 1) that is included in group III copper alloy casts. As all metals and alloys have different casting characteristics and requires their own methods of casting, it is unwise to conclude that the methods employed can be used for all types of alloys and metals. However, reduction of time of 35-60 minutes for a single impeller and reduction of expense up to 15-20 USD per melt was obtained on this particular case.

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