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EXPERIMENTAL ANALYSIS AND ISHIKAWA DIAGRAM FOR BURN ON EFFECT ON MANGANESE SILICON ALLOY MEDIUM CARBON STEEL SHAFT

Abstract: *Burn on/metal penetration is one of the surface defects of metal castings in general and steel castings in particular. A research on the effect of burn on the six ton medium carbon steel shaft for making a roller of cold rolled steel sheet produced at one of the metals industry was carried out. The shaft was cast using sand casting by pouring through riser/feeding head step by step (with time interval of pouring). As it was required to use foam casting method for better surface finish and dimensional accuracy of the cast, the pattern was prepared from polystyrene and embedded by silica sand. Physical observations, photographic analysis, visual inspection, measurement of depth of penetration and fish bone diagram were used as method of results analysis. The shaft produced has strongly affected by sand sintering (burn on/metal penetration). Many reasons may be the case for these defects, however analysis results showed that the use of poorly designed gating system led to turbulence flow, uncontrollable high temperature fused the silica sand and liquid polystyrene penetrated the poorly reclaimed and rammed sand mold as a result of which eroded sand has penetrated the liquid metal deeply and reacted with it, consequently after solidification and finishing the required 240mm diameter of the shaft has reduced un evenly to 133mm minimum and 229mm maximum mm that end in the rejection of the shaft from the product since it is below the required standard for the designed application. In addition, it was not possible to remove the adhered sand by grinding. Thus burn on is included in mechanical type burn on.*

Keywords: *Steel shaft, sand casting, burn on/metal penetration, lost foam casting, polystyrene, fish bone diagram, control chart*

1. Introduction

Since long time sand casting is the most common, versatile, and economical casting process for manufacturing parts, both for large and small parts especially in small numbers. It is also one of the few processes that can produce large ferrous parts, such as shafts, sugar cane crushers, gears automotive engine blocks, etc. Since the sand mold must be remade for each casting, the process is

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labor intensive and relatively dirt.

The quality of castings may be affected by internal and surface defects. On the surfaces of otherwise sound castings, the defect appears as lines which trace the flow of the streams of liquid metal. Various causes may be the reason for surface defects. As mentioned on the works of the article (www.keytometals.com) some of the causes may be oxide films which lodge at the surface, partially marking the paths of metal flow through the mold As per (Ling *et al.*, 2008) mentioned, it has been found that, when hydro-turbine blade castings of ultra-low-carbon refining stainless steel are made using CO_2 cured silicate-bonded sand mould with zircon coating, the burn-on defect mostly occurs on the casting surface closed to the corner and “hot spot” area. This burn-on defect consists of much irregular honeycomb structure; each is about 5-50mm long, 3-10mm wide, and 1.5-4mm thick. The surface defect is very difficult to be removed by fettling; the castings with the serious defect may lead to scrap. According to the above authors too soft ramming is also favourable for the formation of burn-on defect. Since it is impossible to change steel composition and pouring temperature, the simplest and most effective way to eliminate the burn-on defect on the surface of hydroturbine blade castings is to study and find new coatings used for CO_2 cured silicate bonded sand mould. Since the pouring temperature of steel is very high around (1800^{o}C). It has also mentioned that the oxides of metals and refractory debris of the furnace become the source of burn on.

Defect sources may connect with input materials, technology and skilled man power problems. Surface defects may improved by various means. If strength and toughness are critical and cost is not of overriding importance, then castings are often subjected to further processing to improve their properties and qualities. According to (Metals Processing, structures, processing and properties of engineering materials)many of the problems that occur in finished products have their origin in the original casting. Internal defects created during casting can be very costly, since they are usually difficult to detect, and are often not found until later processing stages or even in service. Some defects are caused by simple mistakes, but these are specific to the individual casting process.

According to Kruse *et al.* (2006) surface defects caused by metal mold interaction have been subject for a debate for many years. Traditionally, surface casting defects in steel and iron castings typically have been classified as either burn in or burn on depending up on whether or not there was a recognized glassy phase (burn in) in the defect.

Burn on is one of the problems that affect the quality of sand. Casts my reject or salvaged due to burn on problem. In some cases especially on ferrous metal casting surfaces the strongly adhered sand may not be easily removed with simple grinding. Number of grinding discs and long time grinding as well as machining require large amount of financial expenditure.

According to Strobl (2000) and Brooks andBeckerman (2006) and existing practice, under practical conditions castings, like all metallurgical products, contain voids, inclusions and other related defects or flaw, which cause quality variation. Flaw may make the normal function or appearance of the product to be in poor condition and may lead to the possibility of salvage or, to rejection as well as replacement. Many authors agreed that decision about level of casting defects is dependent upon the defect itself and its significance in relation to the service function of the casting and to the quality and inspection standards being applied in the particular industry or nation. As per Brooks andBeckerman (2006), defects may be originated from the casting design, the technique of manufacture and the application of manufacturing technique as well as the materials to be cast. A defect may arise from one source or from a combination of factors based on, which the necessary preventive mechanism has to be devised. From the above it is clear that defects can be minimized by a clear understanding and identification of their fundamental causes. According to (Roy, 2013) rough surface finish/poor surface finish may occur on sand castings due to high temperature of molten metal or low refractoriness of base sands, or due to poor quality of bentonite or high moisture of processed sands, or soft molds or improper or no painting of molds fuse at the casting surface that stick to the surface of the cast. Roy (2013) recommended that the following methods improve the sand burn on defect. The moisture content should be in the range of 3.0-3.5% for HPML, 4-4.5% for semi-mechanized molding to get good surface According to the author too high moisture makes rough surface and too low moisture makes friable surface; Compactability should be in the range of 42-48% for HPML. The total clay content in process should not be more than 12% and the dead clay content should not be more than 4% (maximum) Acording to (Roy, 2013) the temperature of pouring is very vital for the surface finish of the castings. The tapping temperature of Mild steel should be 1580-1600^{o}C. High pouring temperature causes poor surface finish. The base i.e. zircon or magnesite content in paint is important for getting good surface finish. At least 60% zircon carried by alcohol or water is essential for getting good surface finish. Moreover binder present in the carrier plays a vital role. In ready to use paint addition of external carrier causes poor quality as it contains no binders. The silica (SiO_2) content plays a vital role in getting good surface finish. For low carbon steel the silica content should not be less 98%. Regarding temperature of the sand the hot sand causes rough surface problem. The temperature of the process sand should not be more than 45°C. Finer sands give good surface finish and coarser sands give rough surface. The hot sand causes rough surface problem. The temperature of the process sands should not be more than 45°C. Finer sands give good surface finish and coarser sands give rough surface. Many authors in the work (www.keytometals.com) agreed that compactness of the mold is very important for getting good surface finish of the (Roy, 2013) casting. High mold hardness gives good surface finish of the castings. On the other hand low hardness gives poor surface and swelled mold. Roy (2013) recommended that the position of the ingate plays a vital role for the surface finish of the castings. For steel castings, ingate located at the bottom of the casting gives good surface finish.

Practice shows that when the molten metal enters the gaps between the sand grains, the result would be a rough casting surface. This can also be caused by higher pouring temperatures. Choosing, appropriate grain size, together with a proper mould wash should be able to eliminate this defect. According to (Strobl, 2000;Merten, 2012) show the ideal mold would possess a smooth, impermeable surface capable of being reproduced on the casting of both ferrous and non-ferrous metals. At higher temperatures surface roughness and sand adhesion can be encountered, with loss of appearance and increased dressing costs (Todorov and Peshev, 1984). In some case the molding material becomes infused with metal to form a solid mass, which may be difficult to remove especially if the condition occurs in a confined pocket the casting itself may be scrapped (Merten, 2012; Todorov and Peshev, 1984). Literatures show that one of the reasons for surface roughness or sand sintering is burn on. Burn on is a strongly adhered layer of mold materials on the surface of castings, which is formed 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. Based on the adhering characteristics of sand grain with mold 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 (Todorov and Peshev, 1984).

While in chemical type of burn on sand grain is interacted with reaction products of molten metal and mold materials (Brooks and Beckerman, 2006; Todorov and Peshev, 1984). 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 materials, which are formed as a result of the reaction between mold material components. Sand that contains low melting point materials is mostly 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 since at the boarder of metal mold (at the interface) chemical reaction is formed first, which products may make possible penetration of liquid metal in the form of cavity (voids) (Brooks and Beckerman, 2006; Ling *et al.*, 2008).

Based on statistical data analysis (Todorov and Peshev, 1984) about 12-15% assigned production time is lost on burn on removal. This time improvements have to be 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 burn on. According to (Todorov and Peshev, 1984) 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 that is why it has said to be metal penetration. If the depth is less than the diameter of the quartz sand, burn on can be removed easily leaving marks/traces of sand grains on the surface of castings. As seen in Figure 1, burn on covered the almost the total surface of the cast, which explained that the cast can be rejected easily as the dressing cost will be higher than the cast itself.

It hasmentioned in many research works (Strobl, 2000; Tegegne, 2009) that metal penetrate in the form of void is in the liquid state, 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 or metal penetration is considered to be the presence of vapor (steam) forming metals in the charge.

According to (Brooks andBeckerman, 2006; Todorov and Peshev, 1984), despite earlier assumptions it has been firmly ascertained that metal penetration is primarily responsible for sand adhesion. According to investigations as mentioned above controlling factors both metal and mold variables are involved and penetration into voids in the molding material depends primarily upon the pouring temperature, the pressure head of liquid and thus upon the design of gating system as well as casting itself, orientation and feeding technique associated with a particular casting.

Coating may reduce the problems mentioned above. According to (Xingye, 2012) 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. As explained in the work of (Xingye, 2012) 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”. Application of foundry coating can be closed for mold and core sand surface layer between the liquid metal infiltration jam pore, the channel, reduce the casting penetration. The liquid steel in the casting or lower temperature, the surface will continue to generate metal oxide, the metal oxide and silica sand chemical reactions occur, resulting in the “chemical bonded sand casting surface”. 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.

Coatings as (Xingye, 2012) mentioned 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. Foundry coatings can reduce the mold or core of the radiation heating, thereby reducing or eliminating the sand inclusion defects. Have a certain bonding ability of coating, also can penetrate into the mold and core sand between surface, thereby strengthening the mold or core surface strength and anti scour ability, reduce casting defects of sand flushing. Coatings also improve performance and internal quality of casting surface. In casting coating 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. Casting paint to add some inoculant or alloy elements can also have local breeds or surface alloying, improve casting microstructure.

The quality of casting as mentioned in the work of (Ulewicz, 2002) can be assessed by using quality control instruments such as statistical quality control method, Pareto analysis,Ishikawa diagram, control chart methods, etc. All methods are essential in different condition. The quality of the present experiment was analyzed by using Ishikawa diagram. The Fishbone diagram (also called the Ishikawa diagram) is a tool for identifying the root causes of quality problems. Fishbone diagram find to use the in the following cases: To analyze and find the root cause of a complicated problem; When there are many possible causes for a problem; if the traditional way of approaching the problem (trial and error, trying all possible causes, and so on) is very time consuming and when the problem is very complicated and the project team cannot identify the root cause. With these remarks analyzing the burn on problem of the shaft was carried out using the fish bone diagram.

In practical case, in one of the foundry industry around Addis Ababa city (Ethiopia), of one melt, a bulk mass of 30 tons and a cast mass of 6 tons steel cast shaft for cold rolling of sheet metals was produced and rejected due to burn on/metal penetration problem. The practice of such huge cast in the factory has carried out from cast iron. But for steel casting it was the first trial especially using foam pattern was the new idea of the customer. To clean the burn on from the surface of the shaft (cast) at least 270 grinding discs and 4 months working time have lost. From the information of the industry a total of about 8946 USD excluding the mold materials and other related expenses was lost only for one piece 6 tons of shafts. This implies that there is a big economic lose due to sand adhering (burn on) problem and a remedial action must be established.

Based on the above information from literatures and practical case it is clear that sand adhering defect (burn on/metal penetration) is a function of many variables. Thus analysis of the effect has to be carried out to alleviate the problem.

2. Materials and methods

The shaft material was manganese-silicon alloy medium carbon steel with the composition of C: 0.42-0.55, Mn: 0.9-1, 2% and Si: 0.7-0.95 and other trace elements with the balance of iron. This steel is mainly used for producing equipments and parts applicable in relatively non-sever operation. Composition analysis was made using TRECN portable solid spectroscopy of 4mm minimum sample thickness handling type. Composition analysis (identification) using spectroscopy for ferrous metals was made to estimate the loss of such good quality metal and to identify if there are metallic elements that evaporate easily and facilitate burn on by forming steam.

2.1 Method

Casting method used was sand casting. The pattern was prepared from polystyrene and coated with refractory material. For mold making dry silica sand reclaimed and furnished with fresh sand that was bonded with furan resin (no bake system of mold making) was used. Sand was rammed on the polystyrene pattern. As no specific type of gating system was designed, the feeding head (riser) was used as a pouring cap. Pouring was made from the top through the riser. Since the lost foam process main benefits includes increased dimensional accuracy, increased production rates, increased geometric complexities, less machining and better process control, part of the pattern was made from polystyrene(foam). Since they furnace capacity is small to melt the 6 ton metal, two furnaces were used to melt and pouring was carried out one after the other. The second pouring was made following the end of the first pour.

The pattern (polystyrene) was partially removed from the mold. Polystyrene was partially removed since it was difficult to move the 24 tons mold easily to remove the pattern completely and there was an idea that the polystyrene will completely evaporated without affecting the cast quality. Induction furnaces were used for melting and pouring was carried out by using the teapot ladle. The riser constructed was so prepared in a traditional way without the exact limitation of size and was cylindrical in shape located in a vertical position. After casting and shaking out removal of the adhered sand, burn on and other inclusions was made using grinding discs. About a total of 270 grinding discs (4 USD per disc) were used. In addition to surface finishing, grinding helped to identify the type of sand adhering and degree of adherence. Four months are taken for all these dressing process. After grinding visual examination and measurement of the punctures using Vernier caliper were carried out. There was a desire to machine the surface of the cast, however the visual examination carried out and the measurements of punctures due to sand adherences could not lead to machining operation. Figure 1 shows the sketch of the required shaft.

As explained above, analysis was carried out using physical observation and direct measurement of the defects (metal penetration points). 100 randomly selected defected points were taken and their depths of penetrations were measured using Vernier caliper of 0.01mm accuracy. Photographs with the help of digital camera have made to obtain information for analysis as well.

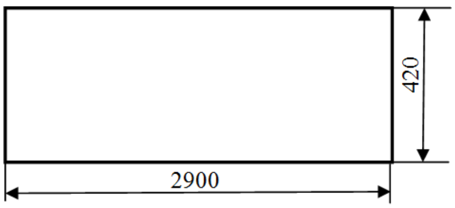

Figure 1. Schematic of the shaft before casting

2.2 Experimental analysis

According to (Brooks and Beckerman, 2006; Todorov and Peshev, 1984)and experience in the world of steel foundry confirmed that sand inclusions can be originated as loose material in the mould cavity when molding material is eroded during pouring, leading either to massive inclusions or to a widespread distribution of individual grains. From the work of (Todorov and Peshev, 1984) it has understood that of the sources of exogenous inclusions in steel castings sands are the predominant constituents, although erosion and slagging of refractories and reactions between molding material and metal oxides contributed too many inclusions. It is also true that mold and core erosion may result from friability due to inadequate dry strength, which leads to the detachment of sand grains. As already underlined above, many factors may be the reasons of burn on/metal penetration. To clearly identify the specific factor(s) for burn on or metal penetration photographs displayed in Appendix 1 have taken and analyzed.

As seen in Appendix 1, sand has adhered on the surface of the shaft strongly in large quantity. From Appendix 1(a) it is clear that the mold material was totally eroded and there was inherent friability of the sand. The adhered sand was not removed by simple shaking (b) and was necessary to use hammering (c). From the observation hammering of the adhered sand took about 6 hrs.

Grinding of the surface was made step by step (d, e). After grinding the surface (f) the final result obtained was not free of metal penetration. As the shaft was newly designed and cast product and as there are no other bench marks or standards to compare the obtained result, it was necessary to measure the depths of penetration and determine the level of the quality of the cast. Hence, after final grinding of the shaft measurements of sand penetration were carried out using Vernier caliper mentioned in the method above. About 100 points, with the major damage was measured in 5 days 20 measurements per day and the results are displayed in Appendix 2. Not only surface defects but also a sub surface defect of up to 107mm depth was observed, where in some specific areas even the diameter reduces to up to 133mm. As seen in the table, this is obvious in the 3rd day measurements. From the table it is possible to observe that the minimum depth of penetration is 11mm and the maximum depth of penetration is 107mm. These defects could not be removed even by machining since the shaft at this point is under sized. As shown in Appendix 1(f), the final diameter required was 240mm but after grinding the final diameter became 133mm minimum and 229mm maximum, which is below the standard.

Figure 2 displays the depth of measured values of penetration. Depths of measurements were taken by part. The first part was the one, which the mold wall was coated by clay coating. There the detachment was less relatively, while the second day measurements took place on partially coated mold and partially uncoated mold part, thus the detachment increased on the uncoated part. The third day measurement was taken on the part where the second pour was made and where there was no polystyrene pattern. The fourth and fifth measurements were taken on the parts where partial polystyrene pattern was used and mold was also coated with clay coatings. Thus relatively small penetrations were observed. From the Figure 2 it is obvious that the 3rd day measurement values are higher than the other days, which confirms the maximum sand detachment from the mold on the uncoated mold wall as well as on the second pouring part of the mold where the second melt pouring caused turbulence and consequently erosion of mold. Since the sand particle detachment from the mold is high and the liquid metal is too hot due to the newly poured metal, liquid metal penetration is high and forms strong glassy penetration. It is clear that when there is liquid metal penetration, sand adhering to the solidified metal is strong and sand could not be removed easily and completely by grinding confirmed the formation of mechanical type burn on. It was thus important to analyze the causes of such defects (Appendix 1).The type of sand used for mold making as mentioned above was silica sand bonded with furan resin. Moreover it was repeatedly used and reclaimed, where possibly iron oxide that is plastic in nature and piled up at higher temperature due to its low refractoriness was included and reduced the quality of silica sand in that when it is pure its fusing temperature is high as a result of which mold material erosion is reduced. More over the iron oxide may be reduced to iron and cause fusing and sticking. The temperature control mechanism used was worked poorly, as a result of which the melting temperature of the mentioned steel reached above 1700ºC (as informed from the operator of the furnace). In contrary the refractoriness of silica sand reaches maximum up to 1580ºC (as per the information from the industry) and starts to collapse above this temperature. In this regard the silica sand was fused and reacted with liquid metal resulting in burn on. Due to the higher temperature the binder was evaporated at earlier time and form steam that reacted with the liquid metal at the same time molding sand was eroded and the detached sand particles penetrated the metal mixed within the molten metal distributing into many parts of the cast shaft. This may be due to turbulence effect. In the molding process no test on sand distribution, shape of sand grain and size was carried out. It is clear that shape, and size (fineness) have a negative effect on bonding strength and permeability. The shape and size determine the distribution of sand and in turn the bond strength is directly or indirectly explained by mold wash (erosion). Most of the time the coarse grain sand is used for large size castings, however in the casting process of the shaft this condition was not considered. The phenomena were confirmed from the physical observation after solidification and grinding the cast.

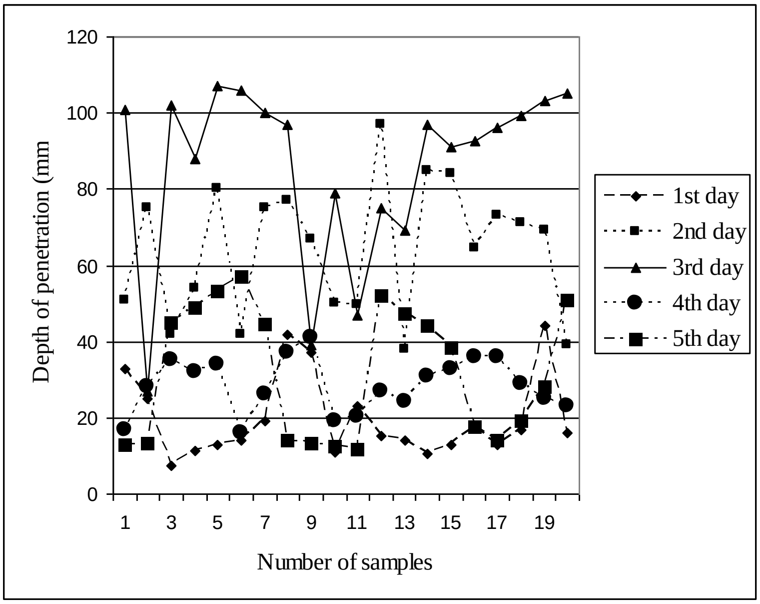

Figure 2. Depth of penetration (mm)

As explained earlier part of the polystyrene pattern was removed from the sand mold and part remained with sand mold. Calcom SA (Understanding the lost foam) explained that some of the problems associated with the lost foam process include: Merging of liquid metal streams or trapping of foam products can lead to internal casting defects and cold shut.

Due to the high temperature thus, the remained polystyrene on the part of mold that was coated with low refractory material, was melted and penetrated the mold material causing erosion of sand particles at the same time the steam of polystyrene reacted with metal formed burn on. At the part of the sand mold, where polystyrene was removed, the sand mold was not coated as a result high mold wash was observed. According to some investigations and from practice, if the sand grains used are very coarse or the metal poured has very high temperature the metal is able to enter the spaces between sand grains to some distance. Thus the sand used for casting the shaft was reclaimed coarse grained with undefined shape. The coarse grained sand was selected due to the fact that the length of the shaft was large enough. Such sand becomes tightly wedged in the metal and is difficult to remove. Pouring of the liquid metal in to the mold was carried out with intervals of undefined time. It was because of the small capacity of the furnace to hold 6 tons of steel charge at a time. These two conditions created high metal penetration (strongly adhered sand in different depths and widths). In one way the high temperature increased flow of metal and the poorly designed pouring system caused turbulence, which consequently erosion of mold and fusion of mold materials including the silica sand was the result. In another way as pouring was made in an interval of time the sand remained on the already solidified surface cast was covered in side by the newly poured liquid metal.

As discussed earlier various causes are mentioned as sources of burn in/burn on casting defect. When the causes are complicated, the cause and effect diagram displayed in Figure 3 helps to analyze the root causes and suggest remedial remarks. Based on this the causes are analyzed (Figure 3) in detail. Comparing to part of the shaft, where polystyrene was removed and un-removed more burn on/metal penetration was formed on the shaft part, where polystyrene was removed. In the un-removed part polystyrene gas and melt reacted with metal and sand that form burn on, which was assumed to be thermal type; in the removed case, the uncoated mold was exposed to high temperature and metal flow was turbulence that caused erosion of the mold and mechanical sand adhering or metal penetration was the result. As the pouring ladle was teapot type the possibility of drosses, slagging and similar inclusions could also facilitate burn on effect. Accordingly, other than the temperature effect, which is commonly known the physical and mechanical as well as technological factors caused burn on/metal penetration (Figure 3). Figure 3 shows cause-and-effect/Ishikawa diagram of burn on/metal penetration on steel shaft (Ishikawa, 1990).

As explained above the metal was over heated and thus fluidity of the metal increased as a result of which viscosity and surface tension also decreased, consequently the flow velocity increased and the flow characteristics was tend to be turbulent being cause of mold erosion, disturbance of liquid metal and raised inclusion reaction. The condition may also lead to mold material friability and consequently burn on.

As mentioned earlier, the shaft was cast using the feeding head as gating system. The shape of the feeding head was cylindrical and was used as a top gating system. The size of the feeding head was not adequate to hold the required amount of hot metal to pour in to the mold and filled as required. These conditions also worsen the problem that deep metal penetration and unfilled part of the cast as well as in-homogeneity of structure were the results. In this regard designing appropriate gating system and riser could alleviate the problem of metal penetration.

Since the cylindrical shaped riser was used as a gating system and the diameter of stream was almost equivalent to the diameter of the cylinder the flow was fully stream type with higher turbulence, where Reynaldo's number may be higher than 3000 (industrial experience for steel) and thus led to again erosion of the mold and disturbance of the liquid metal, where metal-mold material reactions significantly increased as a result of which burn on/metal penetration was developed.

Pouring was carried out using the old ladles, where small refractory particles detached from the mold wall and coating clay can be poured with the liquid metal and increase the formation of drosses and reacting with liquid metal that raise the formation of burn on.

The foundry factory lacks skilled man power, most of the activities have carried out traditionally, the workers were given little attention for this specific casting thinking that the cast could be produced traditionally as usual. The technical facilities are limited old flasks, improperly rammed ladles were used. There was no any experience of using foam pattern especially on such huge castings. Thus complicate the pouring and melting process, which consequently cause the raise of burn on sand.

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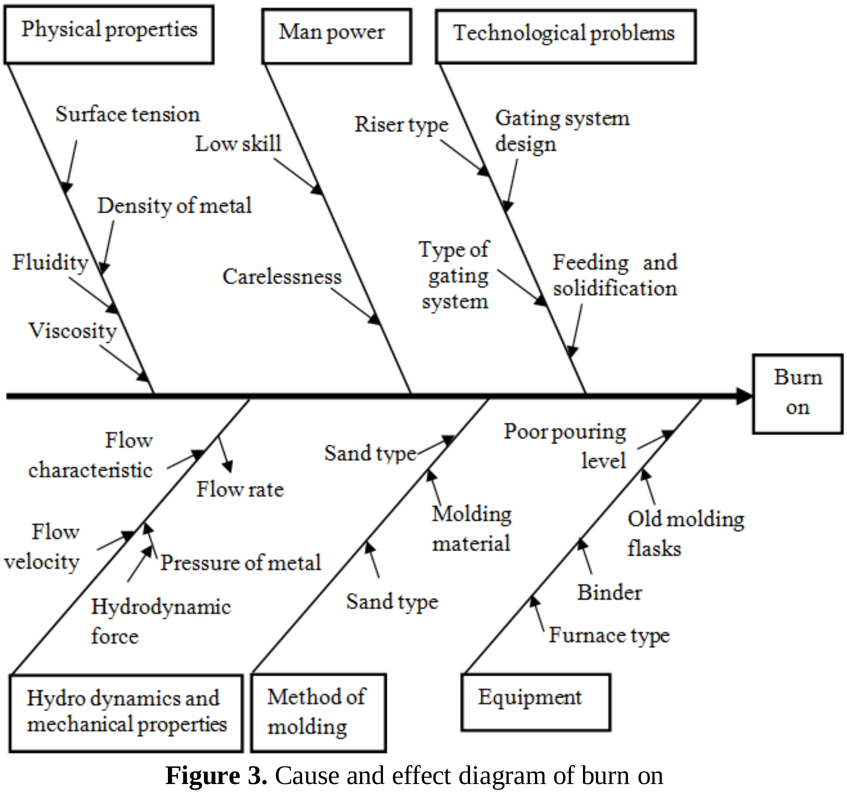

Figure 3. Cause and effect diagram of burn on

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melting process, which consequently cause the raise of burn on sand.

It has known (Tegegne, 2009) that flow of liquid metal has characterized in to three main forms stream flow, fragmental flow and drop type flow. Flow characteristics are depending up on viscosity, flow rate, time of pouring, and height of flow, surface tension and density of the liquid metal. In the condition of the shaft cast the pouring temperature is high the viscosity reduces as a result velocity increases and flow rate also increases. The height of pouring is above 200mm (as per observation), thus the pressure head is high .The conditions lead to turbulent flow of the steel. Obviously in this case the flow character was stream type as the feeding head having large diameter was acted as a pouring cup be the reason for high hydrodynamic force that break the bottom of the mold wall and detach the sand due to its impact. The magnitude of hydrodynamic force which can be calculated by:

$$F_{hd} = 2\rho\pi r^2 \sqrt{2gH}\sqrt{2g(\mu^2 H + h)} \qquad (1)$$

will be greater than 1.62N (Tegegne, 2009) known as a critical value of hydro dynamic impact force in the flow of ferrous metals including steel in which above this value the flow is turbulent and the cast is fully defective on surface and in subsurface due to porosity formation and burn on. Where, F_{hd}-hydrodynamic force, N; P-density of liquid metal, g/cm^3; M-viscosity of the liquid metal; g-gravitational force, m/s^2; H-height of the sprue, mm; H-pressure head, mm.

The manual mold process carried out particularly for this shaft cause soft rammed mold and un equal distribution of sand particles resulted in burn on sand. Generally causes of metal penetration can be much more than the factors displayed in Figure 3. Furnace replacement with large capacity, provision of temperature controlling devices, proper gating system design together with dry sand molding without foam pattern, but by coating proper refractory materials may improve the condition of sand burn on steel castings of various categories in the mentioned industry.

3. Conclusion

It is obvious that sand burn on is one of the serious surface defects of casting, which requires large amount of money for its dressing and developing the remedial method by analyzing the factor is vital. Physical observation, photographic analysis, cause and effect analysis, measurement penetration depth of the cast surface confirmed that the 6 tons cast steel shaft is under dimension due to burn on and the surfaces defect is high that the product will not be functional. This is because of number of reasons analyzed in Figure 3. The required diameter of the shaft when designed was 240mm, however as seen in the table (Appendix 2) and Figure 2 due to the mentioned defects the diameter obtained at the moment is around 229mm (maximum) and 133mm (minimum), that confirms large variation of dimension as well as shape of the shaft. Result of grinding showed that sintered sands could not be removed easily while dressing confirmed that burn on formed on the shaft was mechanical type. Thus appropriate gating system design, material selection and utilization of properly reclaimed sand as well as appropriate mold ramming may improve the situation. Controllable melting temperature is also a primary requirement to protect burn on/metal penetration.

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Appendix 1. Photograph of the produced shaft at different burn on and sand adhering condition

a) Immediately after breaking the mold b) After shaking out

b) After removal of sand by hammering d) After preliminary grinding with riser at the top

e) Continuation of sand removal by hammering f) Final product obtained

Appendix 2. Measured values of penetrated parts on the shaft

No. points	Depth of penetration (mm)				
	1st day	2nd day	3rd day	4th day	5th day
1	33	51	101	17	12.8
2	25	75	27	28	13.28
3	7.53	42	102	35	45
4	11.16	53.8	88	32	49
5	12.8	80	107	34	53
6	14.2	42	106	16	57
7	19	75	100	26	44.4
8	42	77	97	37	14.1
9	37	67	39	41	13.26
10	11	50	79	19	12.6
11	23.2	49.7	47	20.2	11.7
12	15.1	97	75	27	52
13	14	38	69	24.4	47.4
14	10.7	85	97	31	44
15	13	84	91	33	38.5
16	17.7	64.3	92.7	36	17.4
17	13	73	96	35.9	14
18	17	71	99.4	29	19
19	44	69	103	25	28
20	16	39	105.1	23.2	51