Analysis of factors affecting Dimensional accuracy of manganese silicon alloy steel cast components

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Abstract:

Defects in castings affect the final dimensional accuracy of cast components. Different defects including porosities and sand sintering formed on the cast components may be the main causes of dimensional error and mismatch of the component for the designed purpose. The focus of this research was to analyze the factors affecting dimensional accuracy of cast components. Surface porosities and sintered sand formed on manganese steel (46MnSi4) castings formed on gear of weight 925 kg and base plate of 850kg were attacked by surface and sub-surface porosities as well as sintered sands. The porosities/cavities formed on the cast components vary in type, size and distribution on the surface. To avoid the porosities and sintered sand formed on the components cleaning work including hand grinding and machining were done. Due to huge amount of metal removal while grinding and machining, the dimension of casts reduced below the given size and consequently the casts were rejected. The research was conducted experimentally based on quantitative and qualitative approaches. Physical observations, photographic analysis and experimental analysis were used for data collection. Experimental analysis discovered that the maximum porosity/cavity depths on the gear and plate components were 26mm and 25mm respectively. The sizes of porosities were very big and large in number as well as distributed in sufficiently wide areas of casts that accordingly needs removing of these defects. In some points of the casts mechanically sintered sands were observed and required high amount of metal removal by grinding. Due to this the casts became below the required and designed specific dimension and rejected from the product. Cause and effect diagram was used for analysis.Based on the analysis results, the causes of porosity formation were identified. In appropriateness of molding material property, mold preparation method, gating system design, pouring temperature and technique of pouring, material composition and improper utilization of reclaimed sand were considered as the main causes for porosity and sintering problems. Rework or recasting was carried out as a result of which demanded approximately 172 400 ETB (USD 3500). Casting in a controlled condition may help to improve the quality of castings in keeping the dimensions as specified.

Key words: **sub-surface, cast size, specification, porosity defect, rejection of cast**

1. INTRODUCTION

Foundry is the mother of all metal industries and manufacturing. It is one of the oldest of all industries. Authors [1],[2] and [5] stated that even in pre-historic times, as far back as 5000BC metal objects in the form of coins, arrows ,house utensils were used as objects for human use[1,2]. Bronze Age was considered as development era of casting. This time casting is the key for economic development of nations. Using different methods it is possible to cast any metal that cannot be processed by other fabrication methods. Casting is the basis for civilization technology [8].

Casting is one part of metal manufacturing and metallurgy, which covers 80-90%the world metallic products.

As per [6], manufacturing is defined as technological and economic aspects [6, 8]. Technology and economic development of nations is relayed on metal manufacturing and metal processing.

Researchers [6] and [9] described casting as manufacturing of shaped and non-shaped objects like ingot and other regular shapes like round bars, plates, gears, etc. Casts are obtained by pouring liquid metal in to a mold cavity and allowing it to solidify and cool until the required structure and property is achieved [6, 9]. Different defects caused by different irregularities can affect the cast quality. Defects of castings cause deterioration of mechanical properties. As mentioned earlier porosity is among the major defects and formed from different sources in different forms, sizes and shapes including in the form of pin holes, surface and sub-surface porosities, blow holes and discrete type porosities.

The formation of defects in castings can be competent to many factors, including design problem, process problem and material characteristics as well as equipment employed. This complexity makes the defect analysis more of an art-based on experience than an in-depth scientific analysis. Among the defects of castings porosity and sand sintering are the main and difficult types.

Porosity is one of the regular problems which have serious impact on the quality of castings which consequently deteriorate the mechanical properties of a product and as of [15] burn on or sintering 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 longtime grinding as well as machining require large amount of financial expenditure. Author [7] described porosity as the most common problem to customers that should be controlled through better understanding of its nature and source so that quality products can be achieved. According to [9] porosity in castings is due to bubbles of gases and due to a decrease in the solubility of gases during solidification, gases dissolved in a molten alloy are rejected from the solid to the liquid, resulting in an increase in the gas concentration in the remaining liquid. As a result, the last melt to solidify may contain relatively high dissolved gas content that exceed the limit of solubility in the particular metal. While burn on can be developed mostly because of mold erosion.

Sources of dissolved gases in the molten steel may be charge materials containing nitrogen, oxygen, hydrogen and decomposing organic mold binders during pouring .are the most common sources.

According to [10], based on the formation mechanism, porosity in castings may be classed as macro-porosity, micro-porosity. Macro-can be corrected easily while the micro porosity is complex in its nature. Macro porosity is formed in sub surface or in some cases in depth to the cast. Such porosity may be blow hole. While as 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, which causes burn on slags and binders. Choosing, appropriate grain size, together with a proper mould wash should be able to eliminate this defect [13].

Porosity and sintering related defects in shape casting are major causes of casting rejections and rework in industry.

Author [13] considered that porosity may be from hydrogen. Thus hydrogen porosity and shrinkage porosity can be the causes for rejection of cast products.

According [8], most of the problems experienced in metal castings develop because of improper gas control that leads to react with molten metal during the period of solidification and due to turbulent flow while pouring. Moisture from the furnace, lubricants on charge materials can be sources of gases. Turbulence during pouring consequently capture air from the atmosphere as well inclusion and erode the mold which detaches the sand particle from the mold and mix with the molten metal that can stick with the solidified cast surface.

Furnace atmosphere may contain water vapor, CO, CO_2 and SO_2as products of fuel combustion and the normal atmospheric gases such as nitrogen and oxygen [10]. Gas absorption from furnace atmosphere may be facilitated by conditions specifically characterized to a melting furnace.

Author [12] explained that bubbles formed from gases are the most serious problems to develop surface and sub-surface defects. Hydrogen, nitrogen and oxygen are diatomic gases, which are causes of porosities including blow holes and pin holes. Hydrogen and nitrogen contained in the molten steel lead to the formation of various porosity types.

Based on the above discussion and as discussed in[18]castings may be damaged and rejected due to different defects including sand sintering effect ,porosity and other related factors. The main problems in the ferrous foundry section of the case industry, where the said components produced are, mainly porosity related and sand sintering formation on surface and sub-surface on gear and base plate incur cost for reworks and affects the market competent of the case factory. Thus this research analyzed dimensional accuracy factors of gear and base plate castings of Manganese steel using Ishikawa diagram.

2. MATERIALS AND METHODS

The gear and base plates were produced from manganese alloy steel displayed in Table 1. Composition analysis was conducted using ferrous metals spectrometer. Other materials were dried silica sand, resin binder, paint for pattern identification.

Composition (Table1) analysis of metal samples were conducted using TRECN portable solid spectrometer with the minimum holding capacity of 4mm minimum sample thickness

Table1. Materials used casting for casting the components

part	material	Composition				
		C	Mn	S	P	Si
Gear	Manganese steel(46MnSi4)	0.24-0.36%	0.62-0.8%	0.5-0.7%	0.5-0.8%	0.65-0.78%
Base plate	Manganese steel(46MnSi4)	0.40-0.52%	0.92-1.3%	0.8-1.1%	0.85-1.2%	0.91-1.22%

Experimental methodology with both quantitative and qualitative approaches was used to conduct this research. Data was collected using spectroscopy for material composition analysis, Vernier caliper for size measurements of the selected defects on casts .Photographs with the help of digital camera and physical observation. Medium frequency induction furnace, fettling and finishing equipment, sand molding tools, Pyrometer, wooden pattern were used to conduct the experiment. Purposive sampling method was used for this particular case. A gear and base plate produced for sugar factories were selected for analysis in this research.

3. Result and Discussion

To carry out this research data were collected based on physical observation, photograph as well as experiments. The casts in foundry and machine shops were **observed** physically. From the observation it was possible to understand that the method of casting used to cast the selected components in the case industry is sand casting. Mold was prepared from reclaimed sand that furnished with new silica sand bonded with furan resin. Machine and manual ramming were used for mold making. Top and side pouring system for the gear and base plate were the applied methods. Melting was conducted using medium frequency indication furnace and pouring was conducted using bottom stopper ladle with the help of crane. Only cylindrical open riser was used for both cast components. Hand grinding and milling as well as lathe machining operations were used for cleaning process of cast components. After grinding and machining, visual examination and measurement of the diameter and depth of porosities and cavities formed on the surface of cast components were carried out using using Vernier caliper of 0.01mm accuracy. A total 120 measurements were taken randomly and 100 valid measurements were considered for the analysis. For further analysis photographs with the help of digital camera were made.

From the observation it was it was understood that the cast components cast with similar method that is sand casting and poured with the same pouring system (top gating system) and supported with the same cylindrical riser of similar volume were affected by maximum porosity and minimum sand sintering defects (figur1 a,b,c).

The produced gear was designed to serve as pinion gear in sugar cane factories for certain mechanisms and wear due to friction is the possible problem in the other case the base plate was designed to carry out huge machines and is exposed to compression stress. In this regard the cavities and porosities may affect the service life of the components through mechanical property deterioration.

Experiments were carried out in the factory in casting and finishing section. The mold material used was silica sand obtained locally without testing permeability of the sand; patterns were prepared without consideration of draft allowances and shrinkage allowances. Metals sand ratio of 1:5 sand to1: 2% of resin, 0.6% catalyst 100kg of sand was the standard used for mold making in the factory. Fresh sand was added in a limited amount. As discussed earlier in the methodology part the induction furnace with the capacity of 3300kg was used for melting. The pouring temperature was about 1750^0C.The furnace was thus lined with alumina powder. Deoxidizers used for refining purpose were ferromanganese, ferrosilicon and silicon manganese. Ladle was preheated to 200^0C.Dixiders were also added to the melt in the ladle for further refining. While pouring, pouring and solidification time was neglected. Flow velocity, character of flow, flow rate were not taken in to consideration as a result of which turbulence flow was observed and erode the mold and trap air from the atmosphere thus porosity and cavity were formed. After casts were obtained and fettled measurement of porosities and cavities took place. The finished casts were photographed and analyzed that indicated porosities and cavities as well as sand sinters which were not removed by grinding and subsequent machining.

a. Gear component cast

b. Base plate cast component

b. Sand sintering on gear component

Figure1. Defects of cast components, a and b cavities and porosities, c. sand sintering

Measurements indicated that size of porosities and cavities are not similar in all parts of the components and the distribution is not also uniform. From the measurement result one can understand that the total size of the components were below the designed specifications.

Blow holes, surface and subsurface porosities and cavities affect the surface quality of cast and lead to the rejection and rework of these huge components as a result of which financial expenses of the factory raised.

The main problems observed on the cast were blow holes, cavities and mechanical sand sintering that could not be removed from the cast surface as that of the porosities and chemical as well as thermo chemical burn on. 5 days with daily 20 point measurements were required to take the measurements of porosities and cavities. Results of measurements are displayed in Ttable2. Measurements of diameter and depth were considered as all cavities and porosities were approximated to the shape of round and spherical or oval.

Table 2.Measurment of porosities and cavities of the cast component

Sample No.	Firs day		Second day		Third day		Fourth day		Fifth day	
	Diameter	Depth	Diameter	Depth	Diameter	Depth	Diameter	Depth	Diameter	Depth
1	7	20	10	17	7.5	14	7	20	9	13
2	9.5	23	10	13	8	13	8.5	22	7	12.5
3	8	15	11.5	16	8	6	10	17	10	12
4	7	18	5	6	6.5	7	6	5	10	23
5	11	16.5	7	19	6	7	4.5	5	8	22
6	6	4	7.1	15	6	12	4	7	6	21
7	5.5	23	6.2	18	9	4	11	13	5	24
8	10	21.5	8	21	7.5	4.3	9	19	5	6
9	9.8	22	9.3	19	8	6	7	21	8	9
10	5.5	20	9	17	.6	16	8.1	20	5.5	11
11	7.5	19.2	11	13	9.1	17	8	21	9	16

12	4.5	18	10	15	7	11	4.5	18	10	18
13	9.3	21	8	14.5	7	13	5	17	7.5	15
14	7	26	7	7	6.3	10.3	5.5	5	5.5	17
15	6	24.2	4.5	21	6	9.8	7	5	6.2	14
16	6.75	25	5.6	18	9	14	9	11	8	21
17	7	14	6	18	7.2	17	9.2	21.5	8.2	20
18	8.5	12	8.5	10.5	8.4	16	8	15	9	22
19	9	17	8.3	10	7.7	16.2	7.1	17	9.1	6.5
20	11	13	9	18	9	15.1	10	20	7.2	8

From table 2 it is clear that the maximum depth of porosity/cavity reached to 26mm and next to it 25 and 24 mm.

In this case the depths are more than 1mm (standard allowable depth) and the diameter reached to 11.5mm that again is above the practically allowable 2mm diameter in $1mm^2$ area of the cast. From this one can understand that the cast components were damaged due to the mentioned defects and it is obvious that the specified size was disturbed.

The largest depth of blowhole was observed on the 42mm thick base plate subsurface that indicates only 16mm thick plate, which is undesired, was remained in particular parts of the plate.

Maximum diameter of porosity/cavity was registered 11mm in both cases which was also out of the allowable diameter 2mm in 1 square mm area or 1porosity of diameter 1mm in 2 square mm area, which confirms that the cast components are out of the standard design/dimension. The diameter and depth of the cavities and blow holes are displayed in figure 2 and 3 respectively.

From figure 2 it is clear that the distribution of porosities and cavities as well as the maximum diameter reaches to11.5 mm. In practice if the diameter of porosities are greater than 2mm and if the number of porosities/cavities are more than 5 in a particular mm square area or totally on the cast surface the cast component is considered to be out of the required quality. In this case it is possible to take in to account that the casts are out of the designed size and porosities/cavities and sand sintering became the key reasons for undersized cast. As discussed earlier the measurement of depth of cavities/porosities were taken, and as seen in figure 3 the depth distributions vary from area to area of the cast surface and from measurement of day one and day five large depths were registered, which was above 20mm and especially on day 5 measurements the maximum depth reached to 26mm.

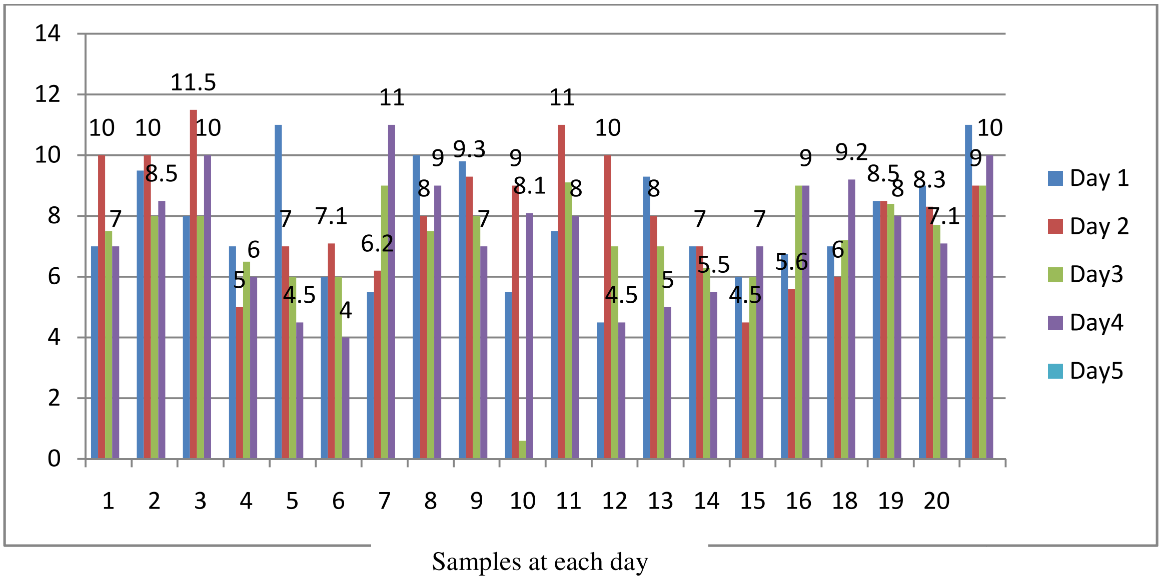

Figure2. Measured diameters of porosities and cavities on each day

As mentioned above the total thickness of the components were 42mm and if the measured values are deducted the size became below the required thickness. This was even without considering the allowances. Thus it is possible to conclude that the thickness of the casts were below the designed dimension and were rejected from the product.

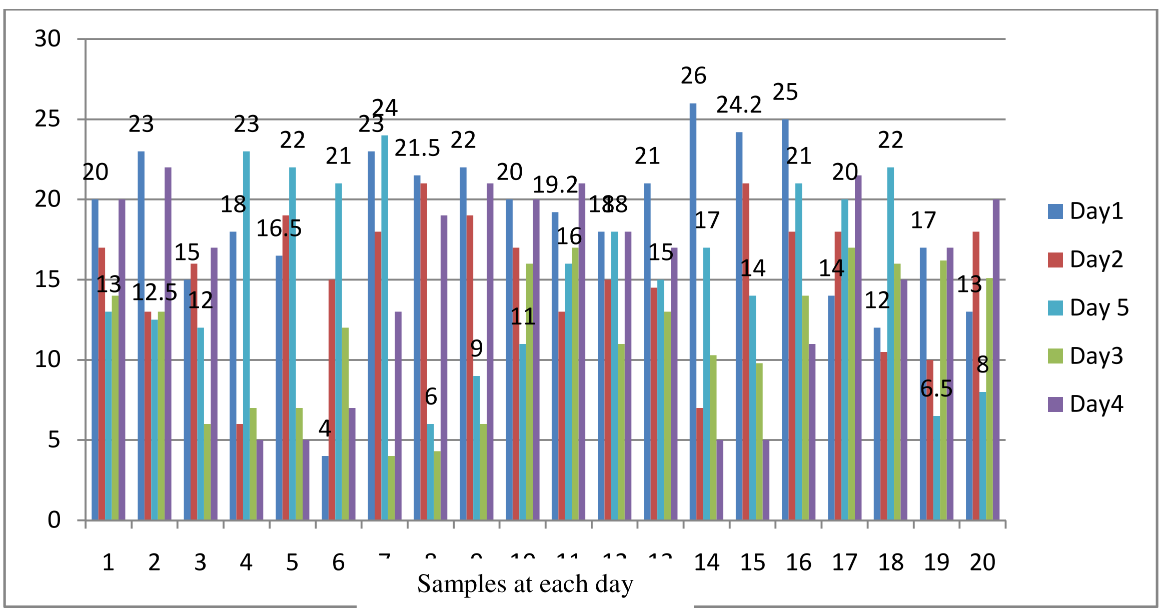

Figure3. Depth of porosities and cavities measured after surface finish

Above the reduction of size was discussed, however in order to produce sound casting the root causes for the formation of such defects has to be analyzed. For this to do, Fish-bone diagram (Figure 4) was used. Through various defects attack cast components in the industry, this research focused only on porosity/cavities and sand sintering problems. Thus analysis was stressed on these particular cases. From the diagram the main causes of such defects were mold ,which is expressed in terms of resin quality, method of molds making, and sand preparation; melting process that relates with pouring method, materials composition and flow characteristics; gating system that contains design of gating system elements and riser design; Solidification of the cast that comprises solidification time and heat transfer problem as well as manpower problem which includes carelessness and level of professional skill.

Mold making in the industry is performed manually and using machine molding methods. Resin was used as a binder and silica sand obtained from Djema River was also used for mold making. On the process, proper compacting and ramming process was not taken place, permeability of the sand is low, resin binders contain hydrocarbon components. These all together lead to gas absorption, mold may be broken and particles of sand may be separated again and these all may cause porosity and sand sintering problems.

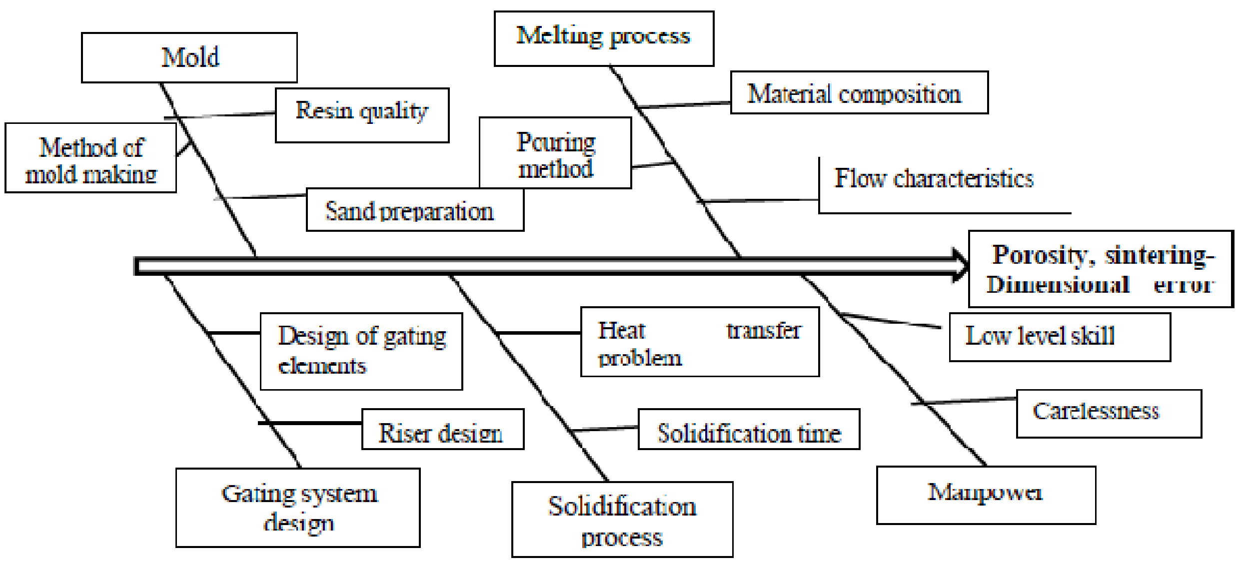

Figure 4 Case and effect diagram for factors affecting dimensional accuracy of casts

If taking the gating system design as a factor it can be analyzed that the gating system used was top gating system which is mostly exposed to air entrapment that facilitates porosity formation in casting. More over the riser was cylindrical open riser of the same design for both cast components that could not contain sufficient amount of hot metal to compensate shrinkage and to give possibility for gas bubbles to escape out from the molten metal .Due to this reason the shrinkage and surface porosities were formed. The pouring basin itself was not properly designed and could not hold sufficient hot metal that could create counter pressure against the entrapped atmospheric air and thus porosity of various kinds were the consequences.

Due to convectional heat transfer problem from at the beginning of pouring there appeared temperature lose and caused early solidification without removing the gas inclusions in the melt .In addition the riser design as explained earlier was also one factor for the early solidification of the melt. As a result gas envelop remained inside the liquid metal and when solidification began the gas envelope escaped from the solid metal leaving a gas pocket which forms blow hole or cavity in the components.

The process of melting began with charging of metals. The charges were scraps and foundry returnees which were not clear and dry. Hence the materials became source of gases and burn on. Besides the pouring was done in the ladle which was exposed to atmosphere .Steel has a capacity to react with oxygen. These were also additional cause for the formation of voids, gases and burn on, which after solidification magnifying defects were formed on the surface of the cast. As steel mostly poured in a turbulent manner, the flow characteristics thus was turbulent (RN>2300) the mixing of air with the melt and erosion of the mold were the possible factors. Also the industry has been serving for long time most employees became careless in controlling the whole process of casting including mold making. Young workers were also employed at the time of this research and observed that they could not manage the whole foundry process. In this case all the mentioned factors became the augmented reasons of loss of dimensional accuracy through formation of porosities, blow holes, sand sintering and similar voids. As a result of poor dimensional accuracy the casts were rejected and a total of approximately 172 400 ETB (USD 3500) were lost for rework.

4. CONCLUSION

From the research carried out it was understood that porosity, cavities of varies types including blow hole and burn on(mechanical sintering) were the defects affect the surface and subsurface quality of the gear and base plate casts and cause reduction of dimensional accuracy. Common factors that cause such defects include mold and making processes, melting process, solidification process and skilled man power problems. Analysis result showed that the maximum depth of cavity was 26mm and the maximum diameter of the cavity was 11.5mma.To remove these defects secondary work was carried out .It was already understood that the cast components became undersized and rejected for rework which, requested about 172 400 ETB (USD 3500) .This problem occurred at one heat. If considering continuity of such problems the industry could be closed. So care must be considered and establishing proper casting process is a critical issue for the case industry.

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