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SURFACES CASTING DEFECT ANALYSIS AND ITS COUNTERMEASURES ON PRODUCTS MANUFACTURED BY ALKALI-PHENOLIC BINDER SAND MOLDING

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Abstract

This paper presents the analysis results of surface casting defects and their countermeasure to find out the root causes of defects, and their mechanisms. Product casting defects have been characterized by visual inspection and SEM/EDX, also collecting production data information. Studied relation between the composition of molding sand and the mechanical properties of compressive strength and surface stability index has been done. The visual inspection results, field data collection, and SEM/EDX analysis showed a rough product surface and the presence of SiO^2 inclusions. The product has been made with an alkaline phenolic mold using reclaimed sand with a compressive strength of 18 kg/cm^2. The study results show that with increasing binder levels, there is an increase in the mechanical properties of compressive strength and surface stability index. They were based on the experimental results of the test block product casting with improved mechanical properties above. Obtained a much better surface of the casting product, and relatively no surface inclusion defects were found. The above experiment shows that the surface stability index is an important parameter the critical value is 90%, and the necessary compressive strength is 20 kg/cm^2. The effect of Loss on Ignition content on mechanical properties is also reviewed.

Keywords: surfaces casting defect, alkali-phenolic binder, surfaces stability index

INTRODUCTION

Casting is the process of making metal products by pouring molten metal into a mold cavity. There are several stages in the manufacture of a casting product, including casting design, mold making, smelting and casting, fettling, and heat treatment. In the mold-making process, the quality of the mold and the core is one of the main factors affecting the quality of the final product (Beeley 2001). Several types of defects may be caused by poor casting mold quality such as gas holes (blow holes or pinholes), cut or wash, penetration, sand dripping or sand crusher, fillet veins, grain, shiny carbon, burnt sand, sand ingress, sticky sand, swelling, scab (Kamble 2016). Today, the types of molds that are commonly used are green sand and chemically bonded sand. The green sand mold is the type of mold that is most widely used in the world because of the availability of raw materials for sand and bentonite, easy recycling, established processing technology, and the lowest total cost per kg of mold compared to other types of molds. However, limitations such as dimensional accuracy, surface finish, ability to make large products, and the soundness of castings, in this case, are overcome by using a chemical bonded sand process instead of a green sand mold with clay or bentonite binder (Brown 2000; Łucarz et al. 2019; Reddy 2019;

Khandelwal and Ravi 2020; Ghosh 2020; Brown 1999). Its caused by the mechanical properties of chemically bonded sand, such as the compressive strength values are up to 38 kg/cm^2, which is higher than the green sand strength values are just about 1.5 kg/cm^2 (Brown 2000; 1999). Alkaline phenolic, Furan, and Phenolic urethane are three commonly used dry sand or chemical bonded sand in foundries worldwide. However, the phenolic alkaline binder is more environmentally friendly than Furan, and Phenolic Urethane is the primary consideration used. In general, the sand mold must meet some of the requirements, including bench life, flowability, formability, refractoriness, permeability, durability, fineness, collapsibility, recycling, and durability of sand molding (Beeley 2001). And The quality of this mold depends on the type of sand used, grain size, resin and catalyst proportions, and curing time (Khandelwal and Ravi 2020).

However, in its use in the field, we encountered several obstacles in metal casting products, as shown in Figure 1. We found surface defects in rough surfaces and sand inclusions based on visual inspection, where the compressive strength of alkaline phenolic sand is <= 18 kg/cm^2.

This article presents the results of the failure analysis of the surface defects casting products, using sand molds with alkaline phenolic binders and the study of the effect of the composition of alkaline phenolic binders on the compressive strength abrasion resistance of the molding sand. The main objective is to find out the root cause and understand the mechanism of these types of casting defects. Then recommendations for countermeasure can be made so that similar defects do not occur in the future.

MATERIALS AND METHODS

Material for Failure Analysis

Figure 2(a) is the high chromium cast iron material product, and Figure 2(b) is the ductile cast iron material product. Those products were produced by sand molding casting in Metal Industries Development Center workshop, Ministry of Industry of Indonesia. They are using reclaimed sand with the alkaline phenolic binder.

(a) (b)

Figure 2. Examples of metal casting products defect are (a) a high chromium cast iron material product; (b) a ductile cast iron material product

Materials for Sand Molding Study

The experiment used an alkaline phenolic resin molding material consisting of sand, resin, and hardener. The sand used is domestic quartz sand with the vendor PT. Silicaindo Makmur Sentosa, Indonesia. A matrix material with a purity of 99.28% SiO_2 and the sieve distribution can be seen in Figure 2. The average grain size

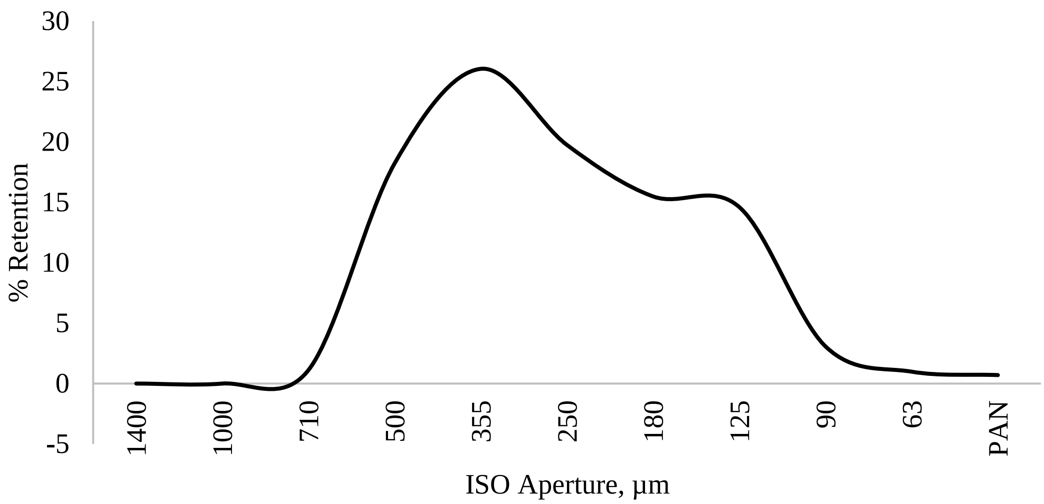

Figure 1. ISO metric sieves distribution, The Average grain size is 352µm

Table 1. Molding sand compositions for the alkali-phenolic process

Sand Label	Resin	Hardener	Sand Matrix [wt.%]	Resin Ratio [% of the Sand wt.]	Hardener Ratio [% of the Resin wt.]
1.2	Fenotec 810	Fenotec H20	100	1.2	25
1.5	Fenotec 810	Fenotec H20	100	1.5	25
1.8	Fenotec 810	Fenotec H20	100	1.8	25
2	Fenotec 810	Fenotec H20	100	2	25
2.2	Fenotec 810	Fenotec H20	100	2.2	25
2.5	Fenotec 810	Fenotec H20	100	2.5	25

is 352µm, and reclaimed sand with mechanical attrition method. The LOI new sand and reclaimed are 0.27% and 1.39%, respectively.

Resins and hardeners use phenolic alkaline resins from the supplier of Foseco with the trademarks Fenotec 810 resin and Fenotec H2O hardener. Experiments were carried out with six variations of the percentage of binders, labeled 1.2, 1.5, 1.8, 2.0, 2.3, and 2.5 according on resin content 1.2%, 1.5%, 1.8%, 2%, 2.2%, and 2.5% by weight of the sand, respectively. with hardener each 25% by weight of resin according to Table 1.

Preparation and Methods

In addition to visual inspection of the surface casting defects, SEM/EDX analysis was carried out to see the morphology and types of inclusions that occurred. Because of considerations of convenience in sample preparation. The material examined is just a sample in Figure 1 (b) nodular cast iron material product because the hardness of nodular cast iron is lower than HCCI (High Chromium Cast iron). Samples of molding sand have been made in the form of cylindrical specimens with a diameter of 50 mm and a length of 50 mm. Both new silica sand and reclaimed silica sand weigh 3000 grams each and then adding resin according to the composition variations in the table above. The sample was stirred manually Because the weight of the samples for each composition is relatively small. Then the mixed sand was put into a standard cylindrical mold and allowed to dry for approximately 10 to 15 minutes. Then the sample is removed from the mold. The samples were then stored for 24 h at room temperature for maximum strength(Łucarz et al. 2019; Ghosh 2020).

Every sample was tested by compressive strength and surface stability index. The compressive strength test was carried out using a Borden compressive strength testing machine, where each sample was pressed until crushed so that the compressive strength value was obtained. At the same time, the surface stability index test was carried out on a modified sieve analysis test machine, where the sample was put into a vibrating test machine for 1 minute. Then the samples are removed and weighed. The following equation determines the value of the surface stability index:

$$SSI, \% = \frac{\text{the final weight of a sample}}{\text{the initial weight of a sample}} \text{x } 100 \; ..... (1)$$

RESULTS AND DISCUSSION

Results

SEM/EDX analysis was carried out to confirm sand silica (SiO_2) inclusions on the surface of the casting product. From the SEM observations in Figure 3 (a), those are a random distribution of grains on the matrix of the metal surface. Then the grain was confirmed by EDX, and the associated peaks can be seen in Figure 3(b-d). SiO_2 inclusions can be seen from the characterization of the metal surface in the EDX spectrum. In spectrum 1. the quantities of Si and O are 45.15% and 54.85, respectively. While in spectrum 2. the values are 49.35% and 50.65% measured in atomic % for Si and O, respectively. The details of the three EDX spectra of the surface defects of castings containing silica inclusions (SiO_2) values measured in weight, and atomic % are listed in Table 2.

Table 2. EDX spectra of the surface defects of castings containing silica inclusions (SiO2) values measured in weight and atomic %

Silica (SiO2) Sand Inclusion	Silicon (Si)		Oxygen (O)	
	Weight (%)	Atomic (%)	Weight (%)	Atomic (%)
Spectrum 1	59.10	45.15	40.90	54.85
Spectrum 2	63.10	49.35	36.90	50.65
Spectrum 3	60.79	46.90	39.21	53.10

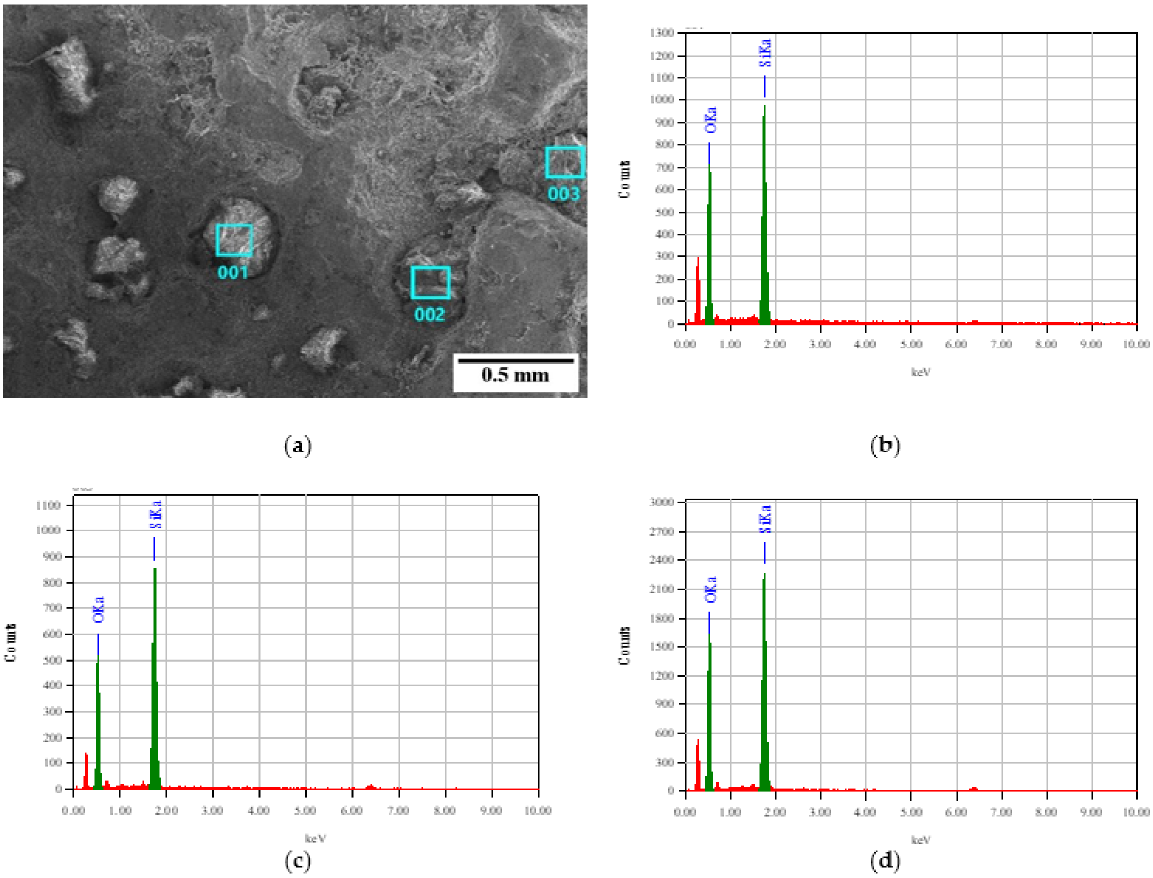

Figure 3. SEM/EDS surface defect analysis result (a) SEM surface morphology image of ductile iron casting product; (b) EDX pattern of silica inclusion (SiO^2), spectrum 1; (c) EDX pattern of silica inclusion (SiO^2), spectrum 2; (d) EDX pattern of silica inclusion (SiO^2), spectrum 3.

Figure 4 shows the results of the surface stability index test for each variation in the composition of the reclaimed sand resin content analyzed. As can be seen, along with the increase in the presentation of the resin composition on the sand, there was an increase in the value of the surface strength index. For resin content below 2%, the surface strength index value is below 90%, while for resin content above 2%, the surface strength index value is above 90%.

Figure 5 shows the compressive strength test results for each variation in the composition of the resin content of new sand and recycled sand analyzed. It shows that for each variation composition, the strength of the sample with new sand is always above the strength of the sample with recycled sand. It occurs because recycled sand has a higher ignition loss value than new sand, with the ignition loss values for new sand and recycled sand of 0.27% and 1.39%, where the loss on ignition is the residual resin that is still attached to the sand grains after the mechanical reclamation process.

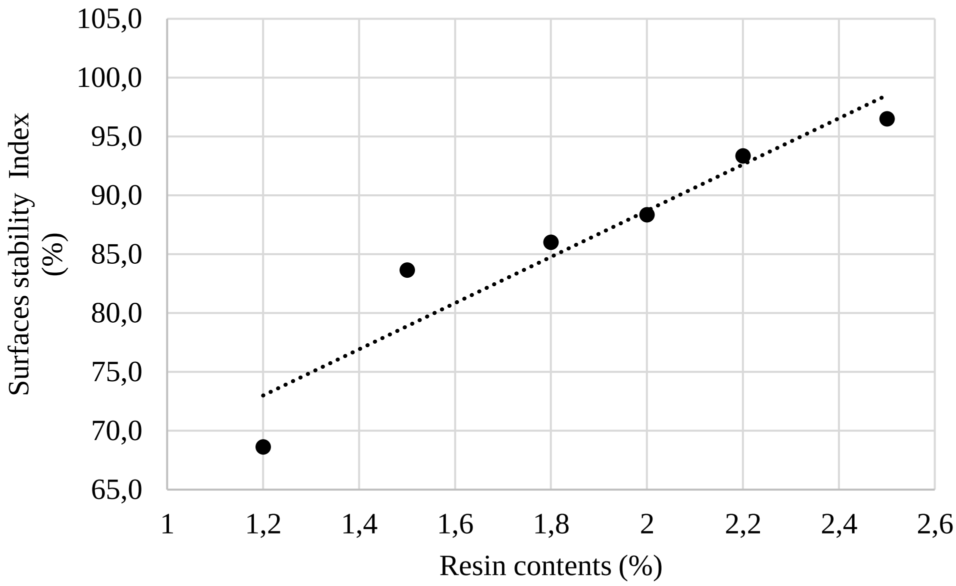

Figure 4. Surfaces stability index of alkali-phenolic molding sand (reclaimed sand)

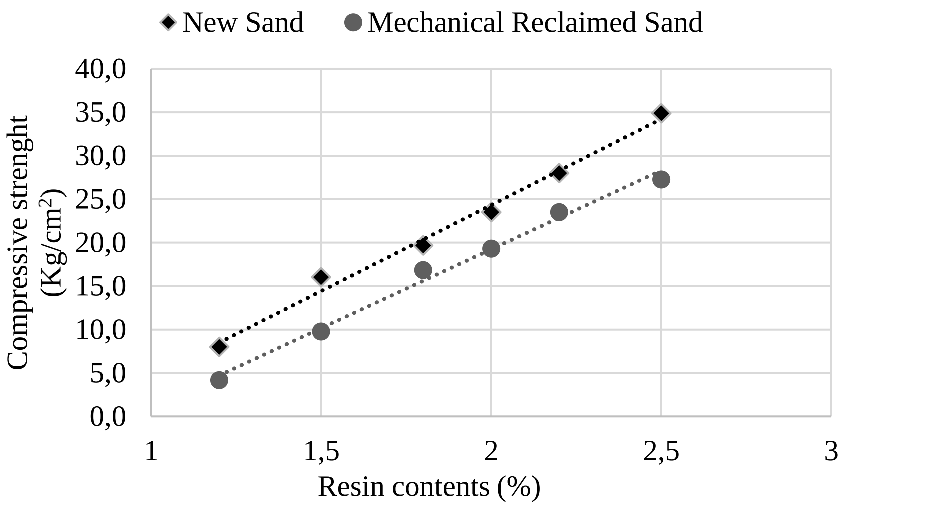

Figure 5. Compressive strength of alkali-phenolic molding sand (new and reclaimed sand)

Figure 6 The following shows the product of the test block casting results. Based on visual inspection, no sand inclusions were found, and the surface was better than the product in Figure 1(a). with a resin content value of 2.2%, the compressive strength of sand was 23.5 kgf/cm^2, SSI was increased to and 90.7%. This was able to increase the abrasion resistance of sand at the time of receiving friction from the molten metal during casting.

The following Figure 7 shows a combination of composition on compressive strength and surface strength index. It can also be seen that molding sand samples with a surface strength index above 90% and the compressive strength must be above 20 kg/cm^2. The minimum surface strength index value is required for molding sand, especially in receiving friction from liquid metal during pouring. Even though this molding sand still has the possibility of increasing the compressive strength and surface stability index after pouring (Ghosh 2020).

Figure 6. Test block product with high chromium material

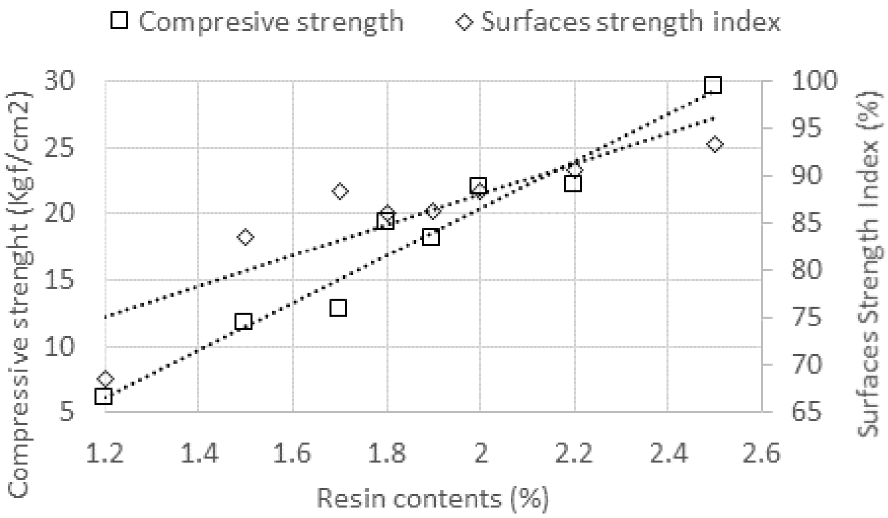

Figure 7. The influence of compositions on compressive strengths and surface stability index

Discussion

Based on visual inspection and SEM/EDX analysis on the surface casting product in Figures 1(a) and (b), the type of inclusion that occurs is silica inclusion. As the result of SEM/EDX confirmation in Figure 3(a-d). The possible cause of the defect is that the surface of the sand mold is not able to withstand the friction of molten metal when pouring molten iron into the mold. This can be identified as a rough surface in some areas because the sand is eroded. Then the grains of sand are carried by the flow of molten metal to other areas. Due to the different density of the sand grains from the molten metal, it floats to the surface, resulting in the appearance of a rough surface and sand inclusion defects on the top surface of the product.

The compressive strength and the abrasion resistance (surface stability index value) can be increased by increasing the resin content up to 2.5%. They are expected to be able to withstand liquid metal when casting, where the casting obtained can vary on the type of material, weight, and type of casting design. By setting the critical SSI value above 90% as applied to the test block casting in Figure 7. the potential for abraded sand can be minimized.

This research was conducted to obtain the optimum composition and compressive strength regarding the surface strength index value above 90%. From the experimental results, the compressive strength value is not only influenced by the composition level but also by the Loss on Ignition (LOI) content of the sand. The LOI can be reduced by adding new sand to reclaimed sand. To obtain a Surface Strength Index above 90%, the composition of the alkaline phenolic resin should be above 2%. Also, the total LOI level should be kept below 3% (Hussein et al. 2013). The effect of greater SSI, LOI, and compressive strength value for various product weight and metals material variations, further research needs to be done.

CONCLUSIONS

This paper presents an analysis of casting product surface defects and how to overcome them. by doing some necessary characterization so that the type of defect can be known, and the root cause can be analyzed. The results of the study can be understood that in addition to compressive properties, the surface stability index is one of the important parameters to produce quality castings. the value of surface stability index >= 90% is a critical value.

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