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THE EFFECT OF USING DUST AS A BENTONITE SUBSTITUTION ON THE CHARACTERISTICS OF RECYCLED GREENSAND MOLDS

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ABSTRAK

Industri pengecoran logam menghadapi permasalahan global terkait pengelolaan limbah debu greensand yang mengandung silika dan clay dari bentonit serta pasir silika, yang berpotensi menimbulkan dampak lingkungan dan kesehatan. Oleh karena itu, penelitian ini menganalisis pengaruh pemanfaatan debu greensand terhadap karakteristik cetakan greensand berbahan return sand. Selain itu, penelitian ini berupaya untuk mengidentifikasi persentase penggunaan debu yang optimal untuk mencapai nilai *green compression strength* (GCS) yang paling tinggi. Studi ini menguji variasi penggunaan debu sebesar 0%, 15%, 30%, dan 45% relatif terhadap berat bentonit. Bila dihitung berdasarkan berat pasir, proporsi ini menjadi 0%, 0,09%, 0,18%, dan 0,27%. Pasir cetak tersebut menjalani beberapa pengujian *compactibility*, *moisture*, *permeability*, *Grain Fineness Number* (GFN), *Green Compression Strength* (GCS), *Dry Compression Strength* (DCS), *Wet Tensile Strength* (WTS), *active clay*, *Volatile Combustible Material* (VCM), dan *Loss on Ignition* (LOI). Penggunaan debu dari cetakan *greensand* di sektor pengecoran logam menunjukkan bahwa debu ini dapat menggantikan bentonit secara efektif. Formulasi ideal untuk pasir cetak meliputi 100% pasir *return sand*, 0,42% bentonit, 0,18% debu, dan 2,9% air. Secara khusus, kombinasi pengikat yang paling efisien terdiri dari 70% bentonit dan 30% debu. Campuran khusus ini mencapai GCS tertinggi sebesar 13,4 N/cm². Nilai GCS yang lebih besar menandakan bahwa pasir cetak memiliki kemampuan yang lebih baik untuk menahan tekanan dari logam cair selama proses penuangan.

Kata kunci: pemakaian debu, pengecoran logam, pasir cetak, *greensand*, *green compression strength*.

ABSTRACT

The metal casting industry faces global challenges in managing greensand dust waste containing silica and clay from bentonite and silica sand, which has the potential to cause environmental and health impacts. Therefore, this study analyzes the effect of greensand dust utilization on the characteristics of greensand molds made from return sand. Additionally, this study aimed to ascertain the ideal percentage of dust required to attain the maximum green compression strength (GCS) value. This study examined dust usage variations of 0%, 15%, 30%, and 45% relative to the weight of bentonite. When calculated based on the weight of sand, these proportions translate to 0%, 0.09%, 0.18%, and 0.27%. The sand underwent several tests, including assessments for compactibility, moisture, permeability, grain fineness number (GFN), green compression strength (GCS), dry compression strength (DCS), wet tensile strength (WTS), active clay, volatile combustible material (VCM), and loss on ignition (LOI). The application of dust from greensand molds in the metal casting sector suggests that this dust can effectively replace bentonite. The ideal formulation for the molding sand includes 100% return sand, 0.42% bentonite, 0.18% dust, and 2.9% water. Specifically, the most efficient binder combination consists of 70% bentonite and 30% dust. This particular mixture achieves the highest GCS of 13.4 N/cm². A greater GCS value signifies that the molding sand possesses an improved ability to withstand the pressure from the molten metal during the pouring process.

Keywords: *using dust, metal casting, molding sand, greensand, green compression strength.*

1. INTRODUCTION

Metal casting is a method in the manufacturing process that utilizes liquid metal and molds to create a shape that is close to the final design of the product. The liquid metal is poured or pressed into a mold that has a cavity according to the desired shape [1][2]. One of the traditional casting techniques that is still used in the manufacturing industry is molding sand [3]. The greensand mold method remains the main choice because of its relatively low cost [4][5]. Greensand molds consist of silica sand as the main component, plus a binder such as bentonite and other additives [6]. Greensand is better suited for the casting process because of its qualities, which include strength, hardness, and good gas flow or permeability [7][8].

The metal casting sector, especially those employing the sand-casting technique, generates considerable quantities of solid waste. This waste comprises foundry sand, dust collected from dust collectors, binder remnants, silica particles, and various metal oxides. In the mold-making phase, silica sand is combined with bentonite, carbon, resin, or other binding agents to create molds capable of enduring high temperatures. Once the molten metal is poured, the molds are dismantled, and the sand is recovered for reuse. Nevertheless, this cyclical process of mold usage and reclamation leads to a decline in sand quality, fragmentation of grains, accumulation of burnt carbon, and an increase in fine particles that become trapped within the dust collection system. This material is referred to as reclamation dust or dust collector dust, which is frequently classified as waste [9] [10].

Numerous studies have indicated that reclaimed sand possesses notable physical and chemical properties that merit additional examination. The dust particles are typically very fine and primarily consist of SiO_2, Al_2O_3, and Fe_2O_3, thereby maintaining sufficient mineral stability to qualify as an additive in molding sand systems. Its fine grain structure has the capacity to affect the mechanical properties, bonding levels, and mixture behavior when combined with either new or recycled molding sand [11]. The existing literature on waste foundry sand (WFS) also highlights its potential for diverse applications, ranging from construction materials to eco-friendly filler options, provided that the management of binder residue, burnt carbon, and thermal characteristics is conducted appropriately. While the properties of WFS can vary significantly across different industries, its high SiO_2 content and thermal stability present considerable opportunities for reuse, including reintegration into metal casting processes [12]. In powder form, this dust has a very fine particle size and can function as a good additive for coarse silica sand [6]. This additive is very important in modifying the properties of the mold specifically [13]. Additives play a very important role in changing the properties of the mold specifically [8][4].

Additional materials such as fly ash, sawdust, coal dust, sea coal, starch, and rice husk are used in limited quantities. These materials can improve the quality of molding sand and casting results [14]. The quality of casting results is greatly influenced by the permeability, green compression strength (GCS), and dry compression strength (DCS) of molding sand [8]. These properties are influenced by the shape and size of molding sand particles and the added binder. In addition, when viewed from the chemical composition, bentonite and fly ash have similar CaO (calcium oxide) content, although the CaO content in bentonite is higher than in fly ash [15]. Fly ash can be an alternative binder in the production of molding sand for casting [16].

The author's preliminary investigation into the dust from dust collectors revealed that this substance possesses a Grain Fineness Number (GFN) of approximately 256.28. Notably, 65.38% of the particles fall within the PAN fraction, signifying a predominance of ultrafine grains that significantly exceed the GFN range typical of commercial molding sand (±35–70). Furthermore, the clay content analysis indicated a total clay percentage of 76.54%, with 41% classified as active clay, suggesting that the majority of the clay fraction continues to serve as an adhesive. In practical terms, these findings imply that the dust could be utilized as an additional binding agent in greensand systems [17].

Initial experiments conducted on newly sourced silica sand-based greensand with a dust addition of 0 – 1.5% have indicated an enhancement in green compression strength (GCS). This enhancement is believed to result from the extremely fine size of the dust particles, which occupy the voids between the sand grains and reinforce the mechanical bond with bentonite [18]. Nevertheless, the application of fresh sand is not a prevalent practice within the foundry sector; the majority of industries utilize recycled greensand. Consequently, additional investigation is required into a scenario that is more applicable to industrial practices, specifically the incorporation of dust as a minor substitute for bentonite in recycled greensand. This strategy not only promotes the efficiency of raw materials but also minimizes waste generation and enhances the sustainability of the foundry operations.

2. METHOD

The object of this study is a green sand mold made from old silica sand, also called return sand, which is used silica sand from the green sand itself. The composition of green sand includes silica sand, bentonite, and water. The composition of green sand used in this study can be seen in Table 1. Samples 1, 2, and 3 used a fixed water percentage of 2.9%, while sample 3 used 3% water. The use of different water aims to obtain a fixed compactibility value, which is 36%. The proportion of bentonite was reduced and replaced with dust taken from the dust collector in the mold area of the metal casting industry. The dust utilized in this research had been previously analyzed by researchers. The dust was gathered from the accumulation of dust in a dust collector used in the metal casting industry. Test outcomes indicated an AFS Grain Fineness Number (GFN) of approximately 256.28, with 65.38% of the sample mass retained on the PAN (the finest fraction of the sieve series). Concurrently, tests for clay content revealed a clay content of 76.54% and an active clay percentage of 41% of the total clay content [17]. Details of the use of dust as a substitute for bentonite are shown in Table 2, and the dust from the dust collector used in this study is presented in Figure 1. The variation of dust usage in this study was 0%, 15%, 30%, and 45% of the weight of bentonite. If calculated based on the weight of the sand, the proportions are 0%, 0.09%, 0.18%, and 0.27%. The percentage of dust usage is adjusted to the standard, namely, the dust content in greensand must be less than 1%.

Table 1. Greensand composition with return sand as the base material

Material	Sample 1		Sample 2		Sample 3		Sample 4	
	%	gr	%	gr	%	gr	%	gr
Silika sand	100	2000	100	2000	100	2000	100	2000
Dust	0	0	0.09	1.8	0.18	3.6	0.27	5.4
Bentonite	0.6	12	0.51	10.2	0.42	8.4	0.33	6.6
Water	2.9	58	2.9	58	2.9	58	3	60

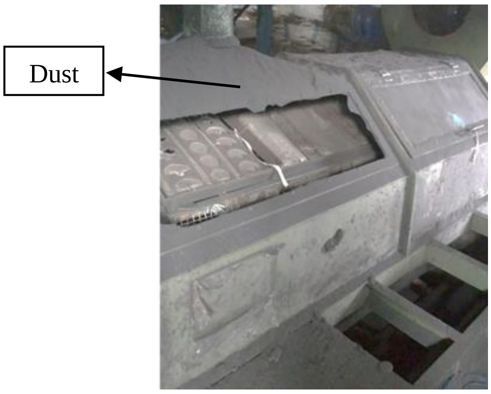

Figure 1. Dust collector in the mold section of the metal casting industry

Table 2. Utilizing dust as an alternative to bentonite

Sample	Binder %		Binder (gr)		
	Bentonite	Dust	Bentonite	Dust	Total
1	100	0	12	0	12
2	85	15	10.2	1.8	12
3	70	30	8.4	3.6	12
4	55	45	6.6	5.4	12

The properties of greensand were evaluated through standard laboratory procedures that are typically employed in metal casting research. It is important to highlight that there is no universal international standard governing all these parameters; therefore, the testing methods are based on laboratory practices that are widely recognized in academic research. The moisture content was assessed using a moisture analyzer, which involved heating a 10 g sample at 110°C until the moisture value was determined. Compactibility was measured with a sand rammer by completely filling the sample tube (sand weight is around 140-180 g), followed by ramming it three times, after which the sample was extracted and weighed. Figure 2 shows the tools for making samples, namely a tube filler and sand rammer. The same samples from the sand rammer were utilized for permeability testing, conducted with a permeability tester at an air pressure of ±3 bar for a duration of 30 seconds. The green compression strength (GCS) was evaluated using a Universal Sand Strength Machine at an air pressure of 6 bar, employing samples formed with a sand rammer. For the dry compression strength (DCS), the samples were initially dried at 110°C for 120 minutes prior to testing on the same equipment. Wet tensile strength (WTS) test samples were prepared using a sand rammer. The WTS was evaluated with a UTS machine for a duration of 29 seconds, with the temperature conditions on the testing machine reaching up to 310°C. The active clay content was analyzed using the AFS Clay Tester, which involved mixing 50 g of greensand with 475 ml of water and 25 ml of tetrasodium pyrophosphate, followed by washing with a rapid sand washer until the water ran clear and drying at 160°C for 1 hour. The grain fineness number (GFN) was determined using a laboratory sifter with 50 g of sand that had been previously tested for clay content. The volatile combustible material (VCM) value was calculated based on the mass difference of a 10 g sample before and after firing at 649°C for 1 hour, followed by a cooling period of 20 minutes. The loss on ignition (LOI) was computed using a similar method, with firing conducted at 1010°C for 1 hour.

(a) (b) (c)

Figure 2. Tools for making samples: (a) sample (b) tube filler and (c) sand rammer

3. RESULT AND DISCUSSION

The test results of greensand made from return sand with variations in dust usage are presented in Table 3. Figure 3 is a comparison of the percentage of water added, moisture, active clay, sample weight compactibility (weight CB), GFN, and permeability. The compactibility value of green sand targeted in this study is 36%, as the foundry sector involved in this study adheres to a standard greensand compactibility of 36%. This figure ensures an ideal equilibrium between mold density (which resists molten metal pressure) and permeability (which allows for gas escape), thereby reducing casting defects that may arise from the mold [19]. To maintain a constant compactibility value, water usage increases with the increasing use of dust as a substitute for bentonite. However, the increase in water usage is inversely proportional to the moisture value, where the moisture value tends to decrease with the increasing use of dust. While active clay tends to be unstable, the active clay in samples using dust is higher than without using dust. The decrease in moisture can be caused by the higher active clay content, where bentonite or clay has a significant ability to absorb water, accompanied by expansion and an increase in volume several times [20][21]. With a constant compactibility value, the weight of the compactibility sample increases with the increasing use of dust. This increase in the weight of the compactibility sample can be caused by an increase in the GFN value, where the sand grains become finer, making the molding sand denser. As the mold becomes denser, the compression strength will also rise. The green compression strength (GCS) and dry compression strength (DCS) improved as GFN and the weight of CB increased. However, this causes the permeability of the molding sand to decrease. This result is similar to that expressed by Hariningsih et al. that the permeability of sand decreases if the GFN value is higher and will increase when the GFN value is lower [8][22].

Table 3. Results of testing greensand molds made from return sand

Testing	Dust percentage (%)			
	0	**0.09**	**0.18**	**0.27**
Compactability (%)	36	36	36	36
Weight of CB (gr)	211.86	212.12	214.92	220.85
Moisture (%)	3.464	3.544	3.405	3.35
Permeability	208	195	193	193
GFN	51.33	42.44	52.96	52.59
WTS (N/cm^2)	0.339	0.289	0.248	0.28
GCS (N/cm^2)	11.6	12.1	13.4	12.8
DCS (N/cm^2)	39.1	33.6	35.4	37.2
Active clay (%)	6.8	7.4	8.2	7.4
VCM (%)	3.769	3.194	3.259	3.345
LOI (%)	7.059	6.29	6.44	6.45

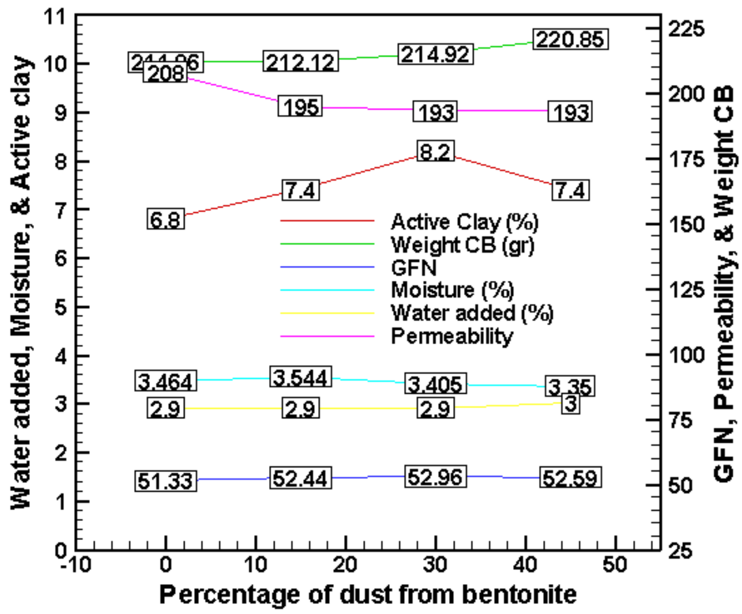

Figure 3. Comparison of dust usage against water added, moisture, active clay, sample weight compactibility (weight CB), GFN, and permeability

Figure 4 illustrates the comparison of moisture, active clay, GFN, GCS, WTS, and DCS. Active clay, GFN, and GCS exhibit similar patterns. The values for active clay, GFN, and GCS in dustless molding sand are lower compared to those that incorporate dust. The peak value occurs with the use of 30% dust, after which it declines with the addition of 45% dust. The peak values of GFN, GCS, and active clay are inversely related to the WTS value. The optimal WTS value is obtained with the application of 15% dust. Additionally, DCS exhibits an inverse relationship with moisture; as moisture levels decrease, the DCS value increases. The optimal GCS was obtained with a molding sand formulation comprising 100% return sand, 0.42% bentonite, 0.18% dust, and 2.9% water, which can also be described as a binder mixture of 70% bentonite and 30% dust (sample 3). This specific composition yields the highest GCS value of 13.4 N/cm². A greater GCS value signifies that the molding sand possesses an enhanced ability to endure the pressure from the molten metal during the mold-filling process.

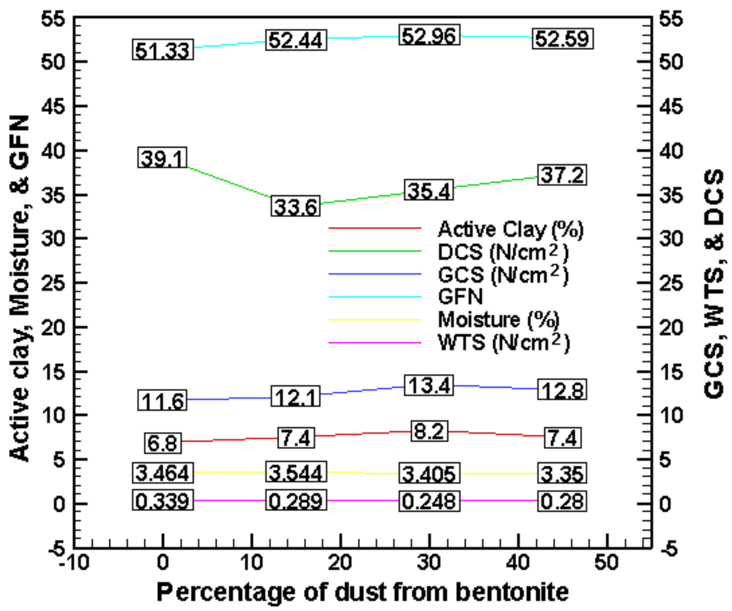

Figure 4. Comparison dust usage against of active clay, moisture, GFN, GCS, WTS, and DCS

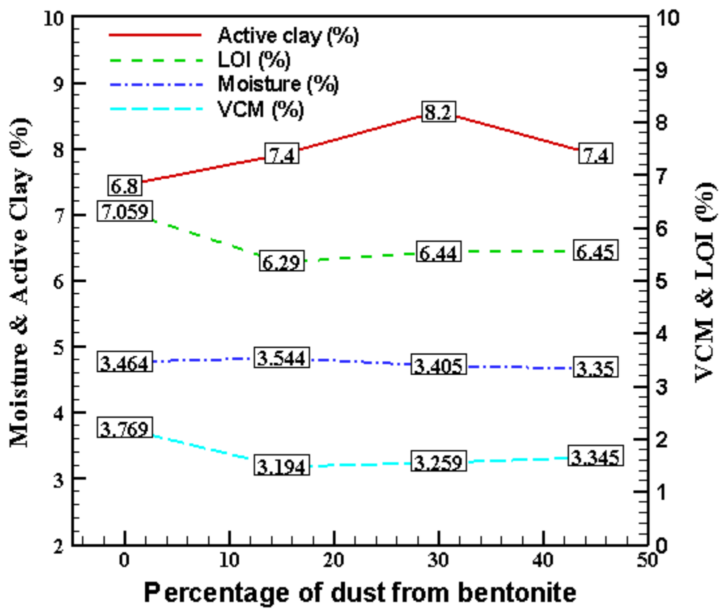

Figure 5. Comparison of dust usage against moisture, active clay, VCM, and LOI in greensand molds

Figure 5 illustrates the variations in moisture, active clay, VCM, and LOI in greensand due to the partial replacement of bentonite with dust collected from a dust collector. The variations in each parameter's response are mainly determined by the mineral composition, clay content, and thermal characteristics of the dust particles.

Active clay rose from 6.8% to 8.2% with a 30% dust addition, as the dust comprises 41% active clay and 76.54% total clay. This serves as an additional binder through ultrafine particles, enhancing the surface area and bonding of the greensand. This observation is consistent with existing literature regarding the role of fine particles in enhancing the initial strength of molding sand [23]. Moisture levels remained consistent (3.19 – 3.48%) despite the increased dust content, as the adsorption capacity of fine clay rises, yet bentonite remains the predominant component, resulting in negligible changes in water requirements.

VCM initially decreased with the addition of dust (from 3.76% to 3.19%) before rising again, reflecting variations in organic composition between the control and dust mixtures. The dust contains carbonaceous and fine organic residues from the reclamation process, which influence volatility when heated. LOI exhibited a similar trend (7.05%, 6.29%, 6.45%), affected by the combustion of organic materials and the dehydroxylation of clay minerals (kaolinite–montmorillonite) at temperatures ranging from 500 to 800°C. The elevated clay content in the dust augmented the material's mass, leading to the release of bound water, which caused the LOI to increase again at higher dust concentrations.

4. CONCLUSION

The application of dust derived from greensand molds within the metal casting sector demonstrates that this dust can serve as an alternative to bentonite. Utilizing the Green Compression Strength (GCS) value as the primary metric, the optimal composition was identified as a blend of 100% return sand, 0.42% bentonite, 0.18% dust, and 2.9% water. In essence, the most efficient binder mixture comprised 70% bentonite and 30% dust. This formulation yielded the highest Green Compression Strength (GCS) value of 13.4 N/cm2. A greater GCS value signifies that the molding sand possesses an enhanced ability to endure the pressure applied by the molten metal during the filling of the mold. While keeping compaction constant, an increase in the proportion of dust necessitates additional water; however, the water content diminishes due to absorption by the dust. The mass of the compacted block (CB) rises with the increasing quantities of dust and water utilized. Both moisture and permeability exhibit a similar pattern: as the proportion of dust escalates, both moisture and permeability decline. The water content and permeability are inversely correlated with CB weight, dry compression strength (DCS), loss of ignition (LOI), and volatile combustible matter (VCM), all of which rise with greater dust application. Conversely, values for active clay, grain fineness number (GFN), wet tensile strength (WTS), and green compression strength (GCS) tend to vary. For future investigations, it is advisable to maintain a uniform water percentage for each variation of dust employed, thereby facilitating the examination of the impacts of pure dust without water compensation.

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