

## Shell Mould Strength of Rice Husk Ash (RHA) and Bentonite Clays in Investment Casting

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**Abstract**— Investment casting process (IC) plays a major role in the modern manufacturing process in providing an economical means of mass production components with intricate shape and complex geometry as demand in various crucial applications including aerospace, automotive, military, biomedical and others. This casting technique, develop shell mould fabrication by coating the required pattern with a refractory mixture which offers the complex geometrical shape and sizes parts to be cast. However, the modern IC approach in shell mould production suffers from zircon's cost and supply instability as it is the main material to be used. Zircon uses as refractory filler for slurry production, and also in the form of sand used as stucco particles, is favoured by the investment casting facilities and industries as it exhibits the most versatile properties such as low thermal expansion and low reactivity to the metal to be cast. During the period of zircon supply shortage, many facilities introduce several alternatives. Currently, the step taken to reduce the cost of primary slurry material is by using some alternate refractory material like, alumina, silica, to be used with zircon for shell mould production. In relation to that, several researches continue to search for alternatives approach for shell mould materials. This research introduces the alternative method in fabricating investment casting shell mould as recognized from investment casting industry located in Sungai Puar of Bukittinggi Padang Indonesia. This industry employs several local resources to fabricate the shell mould. These materials consist of rice husk ash (RHA), and two types of bentonite clays. The bentonite clays were obtained nearly from Kota Payakumbuh in the western provinces. However, this industry suffers from weak shell mould strength and need to be investigated and consulted. In this paper, the investigation on shell mould strength made from rice husk ash (RHA), and bentonite clays were conducted. The strength was measured by its modulus of rupture (MOR) performed in 3 points flexural bending test. The green and fired shell mould strength was determined from five type of slurry composition. The results revealed that the highest green and fired strength obtained were 0.157 MPa and 0.361 MPa from shell mould sample C of RHA (46%) and bentonite (54%) of its composition.

**Keywords**— rice husk ash (RHA); bentonite clay; modulus of rupture

### I. INTRODUCTION

Investment casting (IC) is a metal casting technique, often called “lost-wax” or “lost-foam” casting. IC process offers a high standard of dimensional accuracy, surface finish and design flexibility and is applicable to alloys virtually any composition [1]. It is the key to manufacturing technology that preserves modern requirement of many critical applications [2]. IC benefits in providing an economical means of mass production components with complex geometrical features such as thin walls, undercut contours and inaccessible spaces which are difficult or impossible to be produced by other fabrication methods [3], [4]. The development of aerospace and subsequently engineering

components since the advent of Second World War have made investment casting process is the most versatile modern casting method [5]. It is also a cheaper approach besides other fabrication methods since the waste material is kept to a minimum [6].

In investment casting, there are four main processes involved which are pattern production, shell mould production, metal casting, and post-casting operation. The first process is the pattern production. The pattern is the replica of the cast product. It has the exact geometry of the required final cast product, but with dimensional allowances to compensate its own volumetric shrinkage as well as the solidification shrinkage during metal casting in the shell mould [7]. The most common pattern material is wax [8]. The advantages of using wax as pattern material have been

made it used for mass production. Besides wax, plastic is another pattern material used in investment casting process. When a low production is needed, the plastic material is more suitable than wax due to high tooling cost of die fabrication and intensives labour for wax production. Development of rapid prototyping (RP) has positioned plastic pattern favourable to research facilities in producing prototypes [9]. Advances prototyping machines such as stereo-lithography (SLA) and fused deposition modelling (FDM) manage to be employed as pattern production techniques. The use of acrylonitrile butadiene styrene (ABS) and polycarbonate (PC) have shown efficient and adequate implication in this area [10]. Polystyrene also being employed for economic reasons but its uses are limited since it has the tendency to cause shell mould cracking during pattern removal and required costly die tooling, greater than wax.

Secondly, is the ceramic shell mould process. In this process, a slurry mixture is made by combining a fine size of refractory filler with a binder. This slurry will make up the ceramic coating on the pattern, to produce a shell mould. The key requirements of an investment casting mould are sufficient green (unfired) strength to withstand wax removal without failure, sufficient fired strength to withstand the weight of cast metal, sufficiently weak to prevent hot-tearing in susceptible alloys, high thermal shock resistance to prevent cracking during metal pouring, high chemical stability, low reactivity with the metals being cast to improve the surface finish, sufficient mould permeability and thermal conductivity to maintain an adequate thermal transfer through the mould wall and hence allow the metal to cool and, low thermal expansion to limit dimensional changes within the mould wall and ultimately the casting [11]. In relation to that, the refractory materials play a major role in determining the requirements as stated to achieve a quality ceramic shell mould. Conventional shell mould materials such as zircon, fused silica, alumina, and alumino-silicates are commonly employed by investment casting industry. Zircon is a type of natural mineral that exhibits excellent refractoriness. Besides that, the low thermal expansion, high density, high specific heat, and round shape particles have made zircon is the most favourable refractory in making shell mould for investment casting. However, the use of zircon flour is limited to prime coat only due to its extensive cost and often used in conjunction with fused silica and alumino-silicates. For the slurry binder, colloidal silica is the most used by IC industry, instead of alcohol-based binder like ethyl-silicate that possessed hazardous environmental effect [12].

The process continues by dipping the pattern or a cluster (pattern tree), into the ceramic slurry to develop the face coat. After the primary face coat dried, next dipping is conducted. The drained dipped pattern has then been applied stucco sands, whether by the dipping into a fluidised bed or raining cabinet. The particle size of the stucco is increased as more coats are added to maintain maximum mould permeability and to provide bulk to the mould. Each coating is thoroughly hardened between dipping. The application of stucco is intended to minimise drying stresses in the coatings by presenting a number of stress concentration centres which distribute and hence reduce the magnitude of the local

drying stress [13]. The second main purpose of the stucco is to present a rough surface, thus facilitating a mechanical bond between the primary coating and the back-up or secondary investment [14]. After being dried, the process of dipping and stuccoing is carried out repeatedly until required thickness of ceramic shell mould is obtained. The final coat often called a seal coat, is left without stuccoed, in order to avoid the occurrence of loose particles on the shell mould surface [12].

The dried shell mould will then be subjected to dewaxing to remove the pattern inside. Usually, autoclave dewaxing method is used [12]. Although flash dewaxing can be implemented, the development of the thermal expansion of the shell mould is undesirable. After pattern removal, the shell mould will be fired up to a temperature of sintering, and suitable for the pouring of molten metal. The shell mould will be left to cool for the solidification of the metal inside. Lastly, the shell mould will be break by force or vibration to remove the shell and obtained the cast product. Further post-casting includes finishing, grinding, and inspection is significant to IC industry practices.

Although the broad range of various application offers by investment casting technique, several drawbacks have been reported, regarding the supply shortage and cost instability of zircon flour [15]. Regarding this matter, IC foundries and facilities have been encouraged the search for alternative materials to manage the risk of zircon cost [13]. Several approaches have been taken includes limiting zircon as primary slurry or coating, and employed fused silica and aluminosilicates refractories [16]. Almost all foundries use zircon in their prime coat. It has been estimated that 20% of investment casting foundries use 100% zircon flour face-coats, 20% use all fused silica, 20% a blend of fused silica and zircon (usually 50% by volume or 67% zircon by weight, since zircon has twice the density of fused silica), 20% use 100% alumina (typically, in the aerospace industry), and the rest use other flours including alumina-silicates, Yttria, and zirconia. The most common mesh sizes of zircon are 200, 325, 400, and 600 mesh, or blends of these sizes, with the optimum mesh size selected based on a balance of permeability and surface finish. It has been postulated that as most foundries tumble blasts their parts with media that is coarser than 200- mesh flour, the use of very fine prime flour is unwarranted. In addition, coarse flour allows the wax to more easily penetrate the shell during dewaxing, reducing the likelihood of shell cracking [13].

However, it is inevitable to continuously seek for others materials to resist any incoming risks. In relation to that, it was found that a local Indonesian investment casting industry traditionally employed local and organic materials for mould making. The materials involve rice husk ash (RHA), and bentonite clays, derived from a city of Payakumbuh of West Sumatera Indonesia. This industry is very traditionally-equipped in conducting investment casting process, but the materials in fabricating the shell mould attract the ability for further studies. Moreover, the utilization of rice husk in the various area is encouraging [17].

Rice husk ash or RHA is a by-product of rice husk, waste material in agricultural and industrial and also highly consist of silica composition [18]. The high silica content in the rice

husk ash has attracted interest in discovering ways to use it commercially [17]. Rice husk burning generates new waste, namely rice husk ash (RHA), which corresponds to 20% of husk volume [19]. The silica, namely rice husk silica (RHS), generated from rice husk ash has proved can enhance the strength of ceramic by creating amorphous structure [20].

Various application of rice husk has been reported including as fuel in boilers for steam generation in the power plant, as an agent of silica and silicon compound that brought various research in extracting the silica content from the rice husk ash. Besides that, rice husk also employed to increase the porosity of fire bricks, to enhance its thermal insulation. The burning of organic matter (rice husk) inside the fire bricks will results in porosity, thus, trapping air inside the pores, avoiding the heat lost to the surrounding. Rice husk also is used in making activated carbon to be used as excellent adsorbents. As for rice husk ash (RHA), the production of high-quality flat steel uses RHA as an intermediate agent. Apart from that, the attracting part of the RHA application is in the field of ceramic and refractory industries. RHA commonly used to make an insulating board that results in lightweight and economic insulating board. Besides that, the replacement of kaolinite clay with RHA has the ability to produce more cordierites with lower crystallization temperature and decreases the activation energy of the crystal. Moreover, due to its excellent properties and a source of high silica content, RHA is widely used as a reinforcing agent in the rubber industry, a cleansing agent in the toothpaste and cosmetic industries, and also as an anti-caking agent in food industries. Due to the silica content factor exhibit by RHA the integration of the ash into cement concrete provides better strength and toughness [21].

During pattern removal, the shell mould is subjected to thermal stresses due to heat from flash/autoclave dewaxing method. To avoid cracking, the shell mould must have the sufficient green or unfired strength to withstand the pattern removal [14]. This research intended to determine the strength exhibits by the combination of RHA and bentonite clays, in which, there were very least study to show the utilising of RHA as the only filler for mould making the material. Although, recent researchers have shown the development of rice husk for ceramic refractories and encouraging work have been done to extract the silica from the rice husk [17], [19]. It is found most of the studies, brought an approach to integrating rice husk and rice husk ash (RHA), as an additive to enhance shell mould properties; permeability and strength (MOR). The application of rice husk as reinforcement to improve mould strength had been studied by introducing rice husk into a slurry mixture of zircon flour. The results revealed that the modulus of rupture (MOR) of green state of shell mould that reinforced with rice husk was greater compared to the non-reinforced [22]. As for shell mould permeability improvement, by adding untreated rice husk fibres into shell mould production materials, the permeability of the mould improved significantly [23].

In this research, bentonite clay is employed along with RHA to develop investment casting shell mould. Bentonite is clay frequently generated from the alteration of volcanic ash, consisting predominantly of smectite minerals, usually

montmorillonite. Bentonite is composed of plate-silicate minerals and belongs to the group of minerals known as aluminosilicates. It presents strong colloidal properties and increases its volume several times when coming into contact with water, creating a gelatinous and viscous substance. The special properties of bentonite are the swelling index, water absorption ability, viscosity and thixotropy which make it very valuable clay for a wide range of uses and applications. It is used as a binder material in the preparation of moulding sand for production of steel and non-ferrous casting [24]. In Indonesia, bentonite clay also being studied as purification agent of Patchouli oil to eliminate its colourants [25].

The strength of investment casting shell mould is determined by its the modulus of rupture (MOR) [26]. There are two states of shell mould, in which the strength is crucial. Green strength or MOR describes the state of the shell mould to withstand the stressed during pattern removal. Usually, the green strength of mould is the weak and clear development of increasing the mould green strength can be seen by various of research conducted. The second state of the mould is the fired strength or MOR that describes the easiness of mould removal after casting, to obtain the cast product. Low fired MOR meaning that the mould removal will be easier and does not affect the cast product inside [27].

This research was carried out to evaluate the strength of the shell mould fabricated by using rice husk ash (RHA), and two types of bentonite clays. The shell mould was evaluated its strength in two states of investment casting process, green and fired states. The green state described the state of the shell mould after dewaxing, whilst the fired state described the shell mould after firing process have been done. The strength has been measured describes as modulus of rupture (MOR) by performing 3 points flexural bending test to obtain the subsequent maximum pressure before the shell mould samples are breaks.

## II. MATERIAL AND METHOD

This study was conducted to evaluate the strength of shell mould made by using rice husk ash (RHA) and bentonite clays as the mould materials. The strength of the shell mould is described in its modulus of rupture (MOR), obtained by performing a 3 points flexural bending strength test. The research experiments were carried out by preparing five different slurry composition of rice husk ash (RHA) and two types of bentonite clays as the slurry mixtures. The specification of the slurry compositions of every sample is shown in Table 1. The corresponding investigation procedures are described further in the following subsection.

TABLE I  
SLURRY MATERIALS SPECIFICATION

Slurry Sample	Materials composition (wt.%)	
	RHA	Bentonite clay
A	36	64
B	38	62
C	46	54
D	48	52
E	50	50

### A. Pattern Production

The pattern used in this research is a rectangular polystyrene foam wire-cut to 150mm x 100mm x 50 mm

(length x wide x thickness). The geometry of the pattern was intended to produce a plate shape mould as to perform 3 points flexural bending test to determine the samples strength. Total of 10 shell mould samples was fabricated whereas 5 of the samples required to determine the green strength, whilst the other 5 samples for fired strength. The fabricated samples are shown in Fig. 1. From these shell mould samples, MOR test samples were prepared by cutting the shell mould into a plate-shaped as Fig. 2 showing the green state of MOR test samples, and Fig. 3 showing fired state of MOR samples.



Fig. 1 Fabricated shell mould samples



Fig. 2 Green state MOR test samples



Fig. 3 Fired state MOR test samples

### B. Slurry Production

The production of the investigated slurry in this experiment was composed of rice husk ash (RHA) and two

types of bentonite clays as the mould making materials. The rice husk ash (RHA) was obtained from the burning of rice husk in a firing furnace. The temperature used is 600°C and was left inside the furnace for 8 hours. The desired by-product was ashes with grey colour. Next, the bentonite clays were obtained from the nearby city of Payakumbuh in the western provinces of West Sumatera Indonesia. The main active compounds of volcanic ash clay are alumina-silicates in which having a property of refractoriness. The obtained bentonite clays were in solid big rock forms as in Fig. 4, then these clays were crushed and seized into powder size. These materials were used to make a slurry in four level of the mixture as describes in Table 2. For the first two slurry levels, white bentonite clay was used with rice husk ash (RHA) whilst the last two slurry levels used red bentonite clay with additional of rice husk in the last level. The process of the slurry production was beginning by solving the bentonite clays with water to make a binder solution. The bentonite clay solutions were prepared by mixing 50% of the bentonite clay powder (solid), and 50% of water. Then, rice husk ash (RHA) was slowly added into the bentonite clay solution with specified investigated weight (%). Continuous stirring of the slurry mixture was provided by a stirrer-motor as to achieve a uniform mixture. For the seal slurry, rice husk was added as to store heat during firing since the IC industry conducted dewaxing and firing of shell mould on crucible fired with charcoal. Thus, the shell mould does not have a sufficient heat exposure due to unstable firing by the crucible. So, by adding rice husk, the shell mould will be ignited its own fire to ensure sufficient heat is gained and provide permeability and strength of the seal coat as the burning rice husk transform to ash (RHA), resulted in porosity of the layer to ensure entrapped gas bubble can be escaped during metal pouring.

TABLE II  
SLURRY LEVEL SPECIFICATIONS

Slurry Level	Refractory material	Binder	Addition
Primary	Rice husk ash (RHA)	White bentonite clay	-
Secondary 1	Rice husk ash (RHA)	White bentonite clay	-
Secondary 2	Rice husk ash (RHA)	Red bentonite clay	-
Seal	Rice husk ash (RHA)	Red bentonite clay	Rice husk



Fig. 4 Bentonite clays used as mould materials in this research, white bentonite (left) and red bentonite (right)

### C. Shell Mould Production System

The procedure of the shell mould making for the samples is shown in Table 3. The pattern was first dipped into the primary slurry for 30 seconds to ensure uniform coating. Then the pattern was lifted up and drain for 30 seconds. The first coated pattern was left to dry for 2 hours before the next coating was applied. Next, the second coating was applied and was left to dry for 4 hours. In this approach, no stucco application was involved. The same process of coating application was carried out until the fourth coating or seal coat. After the seal coat was applied, it was left to dry for 4 days. All process involved, starting from the slurry production until the last coating application, along with the drying process was made in a control room with 50% of relative humidity and 24°C of room temperature. After all the shell mould samples were dried, the samples were then subjected to dewaxing to remove the pattern inside. The samples were dewaxed in an electrical firing furnace for 1 hour at 200°C temperature with 20°C/3.4 min heating rates. The completed dewaxed samples (5 samples) were carried out to perform 3 points flexural bending test to evaluate the green strength or green MOR of the shell mould. Then, the others dewaxed samples (5 samples) were fired to be used for determining the fired strength or fired MOR for this research investigation. For fired MOR experiments, the samples were fired slowly for 700°C at the rate of 11.67°C/min in an electrical firing furnace. The fired samples were then left to cool for 1 hour before conducting the 3 points flexural bending test.

TABLE III  
SHELL MOULD PRODUCTION SPECIFICATION

Coat level	Slurry level	Dip time (s)	Drain time (s)	Dry time (hour)
1 <sup>st</sup>	Primary	30	30	2
2 <sup>nd</sup>	Secondary 1	30	30	4
3 <sup>rd</sup>	Secondary 2	30	30	4
4 <sup>th</sup>	Seal	30	30	96

### III. RESULT AND DISCUSSION

All the determined results of RHA and bentonite clays integrated mould are shown and analysed in the subsequent subsections.

#### A. Modulus of Rupture (MOR)

The modulus of rupture (MOR) of green and fired shell mould obtained as shown in Table 5 was determined through 3-point flexural bending test. This test was conducted by using Universal Testing Machine (Model: Shimadzu AGS-10kNXD) as shown in Fig. 5. The modulus of rupture (MOR) ( $\sigma$ , MPa) of every shell mould samples was calculated by using Equation 1. From the Universal Testing Machine, the maximum fracture load (P) is obtained.

$$\sigma = \frac{(3)(P)(L)}{(2)(W)(H^2)} \quad (1)$$

where  $\sigma$  is the modulus of rupture (MPa),  $P$  is the maximum load applied until fracture occur (N),  $L$  is the length of span between two hold point (m),  $W$  is the width of the test samples (m), and  $H$  is the thickness of the test samples (m).



Fig. 5 Universal Testing Machine (Model: Shimadzu AGS-10kNXD) used to conduct 3 points flexural bending strength test in this research

The subsequent parameters are shown in Table 4. The results of the mould strength in green and fired states are graphically illustrated in Fig. 6, showing that the shell mould sample C is having the highest of MOR values for both mould states (green and fired). As the composition of the rice husk ash (RHA) increases, the MOR values of the shell mould samples are increased until it drops as for sample D build from RHA 48% and Binder 52% and slightly increases back for sample E which having RHA 50% and Binder 50% of the composition. As to compare with the conventional materials-mould strength [20], [27], the MOR value of this materials approach is very low. Besides that, the mould was observed to be very brittle and easy to break apart during pattern removal or dewaxing in the green (unfired) state of the mould. On the other hand, the mould was observed to be harder after it has been fired. During the firing process, the elements of the materials are diffused to each other and create better bonding strength of the composites. Therefore, post-firing mould tends to have better strength than unfired (green) mould. However, still, the fired shell mould is brittle and easily crushed and losing the sands particles during handling.

TABLE IV  
PARAMETERS SPECIFICATION FOR 3-POINT FLEXURAL BENDING STRENGTH  
TEST OF MOULD SAMPLES

Sample	Length of span, <i>L</i> (mm)	Samples width, <i>W</i> (mm)	Sample thickness, <i>t</i> (mm)
A	140.0	100.0	24.0
B	140.0	100.0	23.6
C	140.0	100.0	25.5
D	140.0	100.0	27.4
E	140.0	100.0	29.7

TABLE V  
RESULT OF MODULUS OF RUPTURE (MOR) OF THE INVESTIGATED SAMPLES  
IN GREEN AND FIRED STATE

Sample	Green MOR (MPa)	Fired MOR (MPa)
A	0.068	0.102
B	0.134	0.113
C	0.157	0.361
D	0.009	0.027
E	0.111	0.140

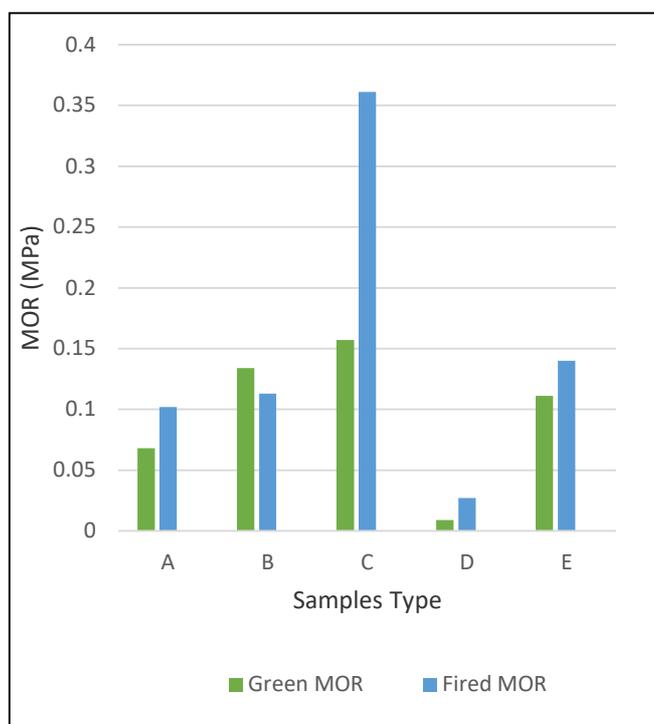


Fig. 6 Graph of modulus of rupture (MOR) for the investigated mould samples in green and fired states

#### IV. CONCLUSIONS

This research was conducted to investigate the strength of investment casting shell mould fabricated using rice husk ash (RHA) and two type of bentonite clays. The corresponding strength described as modulus of rupture (MOR), obtained by performing a 3 points flexural bending strength test. In this research, there was five slurry composition were made of different rice husk ash (RHA) and bentonite clays contents (%). For every slurry specification, two shell mould samples were fabricated in order to determine the strength in green and fired state of the shell mould samples. From the obtained strength (MOR) of

green and fired for all the samples, it is found that the optimum strength (MOR) value (MPa) for both (green and fired) states of the shell mould, sampled C consists of RHA (46%) and Bentonite clay binder (54%) of its composition. Besides that, the shell mould in green state after dewaxing was observed to be very weak and brittle as the particles sand easily breaks. The fired shell mould samples, on the other hand, were harder than the green state shell mould samples. This due to sintering effect that combined or fused the particles of the shell mould materials during the firing process. However, the fired shell mould particles also are observed to collapse during handling easily. As to be compared through previous researchers that implemented rice husk in making shell mould [20], this approach was too weak in the aspect of green shell mould strength. This is due to the weak bonding strength between the particles that were just bonded with water, instead of the conventional binder colloidal silica. The bentonite clay swells during dehydration of water, creating a pull-off force due to the swelling properties. Therefore, the crack can easily occur during the drying process. As for colloidal silica binder, the particles are dispersed uniformly and kept separated by a negative electrical charge on each particle. The outer layer of each particle has a layer of hydroxyl (OH) ions. As water evaporates from the system during shell mould drying, the silica particles are attracted and forced together. The negative charge on each particle is overcome, and a stronger attractive force between the hydrogen (H) of one colloidal particle and the oxygen (O) of another particle form a hydrated silanol bond which links each colloidal particle to the other. In this phase, the colloidal silica will be gelled. This hydrated silanol layer provides the green shell mould strength needed while the ceramic mould is drying. This results in stronger bonding strength between the shell mould particles.

In order to develop this research area, several recommendations can be proposed to conduct further investigation of these shell mould materials. Therefore, the potential of this approach can be highlighted. Subsequently, filling the gap in the searching for alternatives material for investment casting shell mould production. The following recommendations are:

- Employed colloidal silica binder to improve the bonding strength of the shell mould
- Investigates the effect of treated and untreated rice husk ash (RHA) to the shell mould properties
- Investigates the permeability of this materials
- Conduct thermal analysis of this approach
- Replaces zircon with rice husk ash (RHA) as refractory filler and compares the properties exhibits
- Implementing stucco application into this approach so that the bonding strength between the coating layers is improved
- Treating the bentonite clays with calcined to remove impurities
- Develop an investigation on the casting properties using this approach

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