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SUITABILITY OF PLASTER MOULD FOR INDIGENOUS JEWELRY PRODUCTION

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ABSTRACT

The research investigated the Suitability of Plaster Mould for Indigenous Jewelry Production. The investigation involved basic properties of the produced plaster mould for indigenous Jewelry production based on the ratio formulated of the materials and casting were produced using the mould samples, also laboratory instrument were used for the analysis. The results showed that Water absorption of the samples had the average percentage of A = 12.3, B = 4.6, C = 8.92, D = 3.19 and E = 6.77; shrinkage percentage differences of Before Baking and After Baking of the samples A, B, C, D & E are 4.03, 2.85, 2.05, 1.89 and 1.63 respectively while Density of the samples A, B,C,D & E after baking are 1.49g/cm^3 ,1.82 g/cm^3, 1.98 g/cm^3, 1.78 g/cm^3 and 1.83 g/cm^3 respectively. The compression strength of the samples A, B, C, D & E after baking are 158.9N/mm^2, 161.3 N/mm^2, 125.8 N/mm^2, 144.3 N/mm^2 & 141.05 N/mm^2 respectively, while the refractoriness of the Samples A, B, C, D and E were within the range of 1350^{o}C – 1400^{o}C. The cast results indicated samples A, D and E had defects while sample B and C were better. The study therefore concluded that samples B and C are suitable for the production of jewelry.

Keyword: Plaster mould; Basic properties, Cast, POP, Magnesium oxide, Lime

Background of the Study

Every day, in modern society, people interact with a lot of objects that are created through casting. Casting is an important technique used by designers, artists, craftsmen and are found in museums where they replace real items that are not readily available or are too rare to be put on display. The modern industry use various casting techniques to produce things such as toys, car parts, kitchen utensils, jewelry articles and ceramic wares. People around the world have utilized casting as a manufacturing process since 400 BC. The Mesopotamian utilized it to their advantage to cast copper and bronze. The casting process used today is similar to those used in ancient times except for the improvement in technology in terms of materials and techniques (Greer, 2009).

In the modern world there is no place without a part or equipment produced by casting such as in the automotive industry, aerospace, agricultural implements, medical, sculptures and the building industry. Casting involves making a ‘mould’ or impression of model depending on the application intended and the complexity of the model (Ferreira, 2014).

Moulds are divided into two categories depending on the materials used. There are expendable mould and non-expendable (permanent) moulds. Expendable moulds, new mould are required for each casting. Examples are sand mould, ceramic mould, plaster mould, loam mould, skin-dried mould, and cement-bonded sand mould among others. While the non-expandable mould commonly known as permanent mould which are fabricated out of metal or other durable materials and can be used many times for many castings examples are; die casting mould and centrifugal casting mould (Mohammed, 2010). The expendable mould involves the use of temporary and non-reusable mould while the non-expendable mould can be re-used over and over again for mass production (Viridis, 2017). This study is concerned with the suitability of plaster mould (mould properties) which comprises; water absorption ,shrinkage, density, refractioriness and compression strength standard to commensurate the mould materials (plaster of Paris, silica sand ,lime and magnesium oxide) for the production of jewelry. The mould materials and mould properties are the major variable to consider in plaster mould for jewelry production (Mongtomery, Peck & Vining, 2009). The incorrect mould properties can easily result in the production of poor casting (Tang, Fur, Loh, Wong & Lu, 2003). There are various plaster mould processes such as Stereo lithography (SLA), Selective Laser Sintering (SLS), Three-Dimensional Printing (3DP) among others, which are develop to fabricate the moulds for less time consumption and any complex shapes during production. Each process has its own advantages and limitations, considering the cost, flexibility of the system. Among the rapid prototyping system 3DP is the simplest and user friendly used for plaster casting (Wohlers, 1995).

The plaster mould allows the production of complex small articles of non-ferrous metals (Singh & Vern, 2008). Majority of foundries operate efficient and costly laboratories for the control of casting mould materials and for testing a new materials to proportionate its suitability before use. The importance of plaster mould suitability in jewelry casting cannot be over emphasized as it will enlighten and motivate Jewelers in producing intricate jewelries. The research carried out is to ascertain the suitability of the plaster mould and perfect ratio relationship between plaster of Paris and its additives as mould for the production of jewelry. Despite the easy availability of materials for plaster mould making, it was noticed that Nigerian local Jewelers, preferred forging method which has so many difficulties such as time consumption, exhausting of energy and at large no perfection in its final product. The suitability required for the use of the plaster mould includes; water absorption, shrinkage, density, refractoriness and compression strength. The ingredients/materials needed for the mould production include plaster of Paris, silica sand, lime and magnesium oxide. This is consistent with the study of (Mongtomery, Peck and Vining, 2009).

The phenomenon which become derivative forces in this study includes; Nigerian jewelers that are still using the ancient lost wax casting and old forging methods in their production of jewelry with no significant road map of using plaster mould that will enable them conform to modernism. Updating this mould making itself can be a craft of its own, likewise; the technique of using the mould for the production of jewelry. This is because plaster mould plays significant role on the socio-economic importance of small and medium scale production of cast parts and as materials needed for its suitability as mould for jewelry production.

Jewelry is a craft that uses a lot of materials and techniques which could be learned as formal or informal craft. The materials are easy to work with and affordable.

Difficulties encountered by jewelers are; lack of knowledge of using plaster mould to replace the ancient lost wax casting and forging techniques in casting jewelries, material selection, time consumption, exhausting energy and at large no perfection in its final product. Despite the easy availability of materials for plaster mould making, it was noticed that local Jewelers, in Nigeria preferred forging method than conforming to modernism in jewelry production.

Most existing literature failed to explore the suitability of plaster mould for jewelry production using indigeneous materials which includes the study of Brian (2003); Young (2012); McGrath (2012). The study will explore to what extent that jewelry making business, creates entrepreneurs and thereby contribute towards economic diversification and to reduce dependency on the oil sector. Jewelers must be innovative in assessing opportunities through effective skills in product innovation (Musa, Wuritka & Zipporah, 2015).

Studies have been conducted on the role and suitability of plaster moulds in production of non-ferrous metals product (medical equipment, Automobile parts and Jewelries among others) through SLS, SLA and 3DP processes at different times in developed countries, some of these studies include that of (Brian 2003; Young 2012; McGrath 2012; Thiel, Zieglar, DZie, Konski & Joyce 2007; Wohlters & Terry 2012; Wohlers, Terry & Tim 2013). Meanwhile, no clear justification indicating the studies undertaken on techniques for production of jewelry using indigenous material in Nigeria. Exploring meanwhile the use of plaster mould technique could ease time and energy consumption, reduce defects on intricate jewelry product. This study examined the suitability of using plaster mould for indigenous jewelry production by determining the basics properties (water absorption, shrinkage, density, refractoriness and compression strength) of the mould and castings were produced using mould samples.

Materials and Methods

The reliability of the mould properties depend solely on the plaster mould materials (POP, silica sand, lime and magnesium oxide) ratio and the accuracy of data collected from the instrument used such as (speedy moisture tester (Ridsdale), Ridsdale-dietert compression strength machine, Ridsdale-dietert ramming equipment, carbolite furnance, Mettler electrical balance, inferred heating machine). The methods used in conducting the research work is in line with the aim of the study based on the significance of the data to the research topic. The study utilized the experimental data source which basically relies on the materials mixing ratio that gives mould characteristics. Data were obtained from the instrumental results of the plaster mould properties analysis. This is consistent with the study of Holmer, (2015).

Materials and Tools

The materials used were bought from the market in Jos, Plateau state Nigeria and percentage ratio was used as it offers several advantages which provides greater precision of the sample size. Materials used are POP, silica sand, lime and magnesium oxide, distilled water and model (pattern). Tools includes: oil (releasing agent), fencing materials, flat chisel, measuring cup, bowl, and wooden mallet, mask (nose, ear, and mouth). This is consistent with the study of Cocham and Cox, (1992); Mongtomery, (2009).

Variables of the Study

The variables of the study comprise the materials of the mould and their various properties. The properties of the plaster moulds includes water absorption, shrinkage ,density ,refractoriness and compression strength while materials or ingredients for the study includes the plaster of Paris, silica sand, magnesium oxide and lime. The properties of plaster mould will be directly affected by the proportion of its ingredients/materials, to really have a suitable mould for casting jewelry, it requires a detail understanding of the raw materials, laboratory tests results and the production equipment.

Sample preparation

The samples were produced out of the following materials (POP, silica sand, lime, magnesium oxide, distilled water and model) through the percentage ratio as it offer several advantages which provides greater precision of the samples dimension and mixture. This is consistent with the studies of (Cochram, 1992; Mongtomery, 2009). The following tests were conducted; water absorption, shrinkage, density, refractoriness, compression strength and the production of pendant- jewelry samples with the formulated plaster mould.

Plaster mould ratio formulation

Based on the range of individual materials proportion suggested by Bobby (2014) for the plaster moulds formulation, the average proportion achieved using ratio recommended by ASTM 212 discovered that poor proportion of the materials will lead to poor production of the moulds and inturn the casting.

New plaster mould body formation

Table 1: New plaster mould body formulation:

Sample	POP	Silica sand	Lime	MgO
A	70	22	4	4
B	50	40	7	3
C	45	50	4	1
D	60	35	3	2
E	55	40	4	1

Key: MgO – Magnesium oxide; POP – Plaster of Paris

Water Absorption Test

Aim: Determination of water absorption percentages of the plaster mould

Apparatus: digital weight balance, tray dryer (armfield model), aluminum bowl and distil water.

Procedure: The sample of moulds produced were air dried for two days, and further dried for a period of 6 hours using the tray dryer (armfield model) at a temperature of 10^{o}C this experiment took place in Metal and Jewelry studio of the department of Industrial Design ATBU Bauchi. The samples were removed and fired at 600^{o}c to enhance complete dying of any moisture condition, the weight of dried samples were measured and recorded as fired weight. For effective absorption test, the samples were immersed completely in distil water for two days which was enough time for the samples to completely get saturated or soaked. Samples were removed, weight and recorded as soaked weight.

Formula: $A = \frac{SW - FW}{FW}$ (according to Bobby, 2013)

Where:

A = Absorption

SW = Soaked weight

FW = Fired weigh

Shrinkage Test

Aim: To determine the change in size on dried and fired plaster mould for Jewelry production

Apparatus: POP, Lime, MgO, Silica sand, ruler, HB pencil, distil water, mineral oil and wooden block

Procedure: This experiment was carried out in Metal and Jewelry studio of the department of Industrial Design ATBU Bauchi. Plaster of Paris, its additives (silica sand, lime, MgO) and distill water were mixed thoroughly base on ratio as stated. The mixed was poured into the wooden block (5cm x 3cm x 2cm) and was allowed to solidified, afterward the wooden blocks were removed, and the moulds were allowed to dry in a tray dyer at 10^{o}C for 12 hours. The moulds were then baked in an electric oven at 190^{o}C for two hours. The readings were recorded before and after baking, the formula below as suggested by Umar, 2000:

Formula: $DS = \frac{OL - FL}{OL} = \frac{100}{1}$ (% shrinkage)

Where

DS = Dry shrinkage

OL = Original length

FL = Fired length

% = Percentage

Density Test

Aim: To determine the weight of the samples in relations to compressive strength

Procedure: This experiment was carried out in Metal and Jewelry studio of the Department of Industrial Design ATBU Bauchi. The weight per unit of volume of a substance is the density of that substance, the weight of the plaster moulds produced were weighed before baking using digital weight balance, the values were recorded, whereby the length x breadth x height of each samples were calculated to obtained the volume. The formula below was adopted and results.

Formula: Density = $\frac{Mass}{Volume}$

Bulk Density Test

The bulky density of a given material is the ratio of the mass of that material to its bulk volume, that is, the volume of material plus the pores in that material. In this experiment, the bulk density was achieved by soaking the samples in distil water for three days. The length, width and height of the moulds were measured and recorded in centimeter. Digital weighing balance was used to weight each sample to the nearest grams. The results obtained were used to first calculate the plaster mould bulk volume (L x W x h) cm^3, then consequently the bulk density and the result is expressed in g/cm3, the bulk density is guided by the format below as suggested by Soyinka, 2015

W_1 = weight of dry sample

W_2 = weight of test sample soaked in water

W_3 = weight of samples soaked and suspended in air

D = density of immersion

Refractoriness Test

Aim: To determine the fusing temperature of the plaster mould used for jewelry production.

Apparatus: Carbolite furnace RHF 16/15 model, refractory body (synthetic) of 2000 C capacity, honey and mortal.

Procedure: The experiment was carried out at National Metallurgical Development Centre (NMDC). The plaster moulds labeled A – E were crushed into crystals form, and stick with honey on the synthetic body (crucible) of 2000^oc capacity and pressed at 300KN for easy circulation of heat and was place inside the carbolite electric furnace. The samples were observed at various temperatures until fusion (sintered) took place. The sintering temperature were recorded.

Compression Strength Test

Aim: To determine the compression strength of the plaster mould for jewelry production.

Apparatus: Tray dyer (armfield model), digital weight balance, compression strength machine 100KN capacity model CT 950, serial No. 800

Procedure: The produced mould samples were dried in tray dyer in Metal and Jewelry studio of Industrial Design ATBU Bauchi, after dying the samples were taken to Civil Engineering Department of the same institution for the compression strength test. The well labeled samples A – E moisture contents were determine using the speeding moisture tester, the samples were individually transferred to the compressive testing machine – model CT 950. The samples were mounted in turn on the machine and load was applied by operating the pump handle in an anticlockwise movement till it fracture or failed. The breaking point was shown on the dial and recorded.

Mould Preparation

Aim: To achieve cavity using pattern for accuracy in casting

Apparatus: Core boxes, pattern (pendant), distil water, POP and additives, spatula, stirring rod, bowl, mineral oil and tray dyer and wooden block.

Procedure: One piece mould was produced from commercial plaster of Paris, Silica Sand, lime and Magnesium oxide, measurement of materials was according to table 1, ratio procedure. The pattern used was a pendant, it was placed on a flat table and spread with mineral oil, which served as the parting agent, the wooden block was also oiled, the mixture was individually mixed with distil water, to achieved its paste form. The wooden block was placed over the pattern and the paste was poured, it was allowed to solidified after 20 minutes, the wooden block was removed, the mould formed was also removed and the pendant (pattern) was left for the other until the five moulds were produced with the cavity of the pattern. The moulds were allowed to dry in the studio for two days, the moulds were further dry in tray dyer for 30 minutes at 10^{o}C which are then ready to accommodate the molten brass for jewelry production.

Production of Jewelry Articles (casting)

With the five samples of plaster mould produced (A-E), on each was the pattern cavity for the cast, brass was used;

Aim: To determine the castability of the five plaster moulds for Jewelry production.

Instrument/Materials: Straps of ornamental brass, forge, tongs, crucible, flux (borax), fuel (charcoal), pattern (pendant), bellow, brass brush and lemon.

Procedure: In order to test the effectiveness of the plaster moulds labeled A – E, with the same cavity on the sample of a pendant purchased from the market in Jos. Ornamental brass scrap was used as recommended by (Joel, 2016) due to its high ductility and malleability, the brass was put in a crucible and placed on the forge as the fire furnace and lighted. Bellow as compressed air was used to enhance the burning; flux (borax) was added to catalyze the melting process of the brass, as it melted before pouring, slag as impurities over the melt was removed and the molten brass was poured into each of the mould (A – E) gently, and allowed to solidified for about 30 minutes, after solidification, the final works were removed and observed for proper recommendation.

Results and Discussions

Water absorption

Sample A = 12.37%

B = 4. 69%

C = 8.92%

D = 3.19%

E = 6.77%

Samples A, B, C, D and E of different ratio additives and water content of five samples each, their average percentages were 12.37%, 4.69%, 8.92%, 3.19% and 6.77% respectively. The standard range of water absorption is within 3.5 to 4.5% for any plaster mould of casting non-ferrous metals where all the Jewelry materials inclusive as recommended by ASTM 212, and Raghwendra, (2015). From the five samples been investigated it was discovered that sample D is within the limit therefore, other samples need modifications in water absorbency (which is proper control in soaked mass) to meet the standard which balance between porosity and density for plaster mould (Z corporation, 2004). It is obvious therefore that samples A, B, C and E absorb moistures too much excluding the sample D.

Shrinkage

Sample	Length %	Width %	Height %
A	1.57	4.06	5.36
B	1.18	1.95	5.51
C	1.19	1.97	2.87
D	1.37	1.92	2.33
E	0.99	1.62	2.34

The values recorded as the shrinkage levels from all samples in length, width and height A, B, C, D and E are (L= 1.57, W= 4.06, H=5.36), (L= 1.18, W= 1.95, H= 5.51), (L= 1.19, W= 1.97 H= 2.87), (L= 1.37 W= 1.92 H= 2.33) %, and (L=0.99, W=1.62 H=2.34) % respectively. The average volume before baking of samples A, B, C, D and E are 36.56, 33.93, 32.09, 34.27cm^3 and 33.34cm^3 respectively, while the average volume shrinkage after baking of samples A, B, C, D and E are 34.17, 12.68, 6.73, 6.13% and 3.75% while the differences from the before and after baking in volume of the samples A, B, C, D and E are 4.03, 2.85, 2.05, 1.89 and 1.63 according to ASTM 212 only samples C, D and E have the required level for the plaster mould.

Density results

Sample	Before Baking g/cm^3	After Baking g/cm^3
A	1.49	1.49
B	1.74	1.82
C	2.02	1.98
D	1.74	1.78
E	1.85	1.83

Compression strength test

Sample	Before Baking N/mm^2	After Baking N/mm^2
A	158.90	158.90
B	148.22	161.36
C	125.80	125.80
D	121.12	144.30
E	142.00	141.05

The density and compression strength of the samples

Samples average density before and after baking in g/cm^3, before baking the density of A, B, C, D, and E are 1.49, 1.74, 1.98, 1.74 and 1.85 respectively, and after baking A, B, C, D, and E are 1.49, 1.82, 2.02, 1.78, and 1.83 respectively. The compression strength test results before baking of samples A, B, C, D, and E are 158.90, 148.22, 125.80, 121.12 and 142.00 respectively, while after baking of samples A, B, C, D and E are 158.90, 161.36, 132.52, 127.60 and 141.05N/mm^2 respectively. The results of sample B and D showed that the increase in density the mould strength increases, this agrees with the study of (Nicholas, 2008; Khan, 2004) while the decrease in density the mould strength decreases, also the density in sample A did not vary before and after baking shows that there is no baking impact in strength, density and porosity. The samples A, and E needs modification in additives to possess the required density, compression strength characteristics for Jewelry plaster mould while samples B, C and D possess the necessary requirements in terms of compression strength and density as plaster mould for casting Jewelry (Nicholas, 2008; Khan, 2004).

Refractoriness Results

Sintering T^o	**Sintering T^o Sample A**	**Sintering T^o Sample B**	**Sintering T^o Sample C**	**Sintering T^o Sample D**	**Sintering T^o Sample E**
1350^oC	Sintered	-	-	-	-
1400^oC	-	Sintered	Sintered	Sintered	Sintered
1450^oC	-	-	-	-	-
1500^oC	-	-	-	-	-

Refractoriness Test

From the result of the refractoriness test all the samples can be termed refractory material as their sintering points are above 1350^0C analysis and comparison of the results with the required practical values for non-ferrous casting is (280-900) (Musa, 2017). The refractoriness results showed that all samples can be used for casting of all non-ferrous metal alloys in Jewelry production.

Casting results

The ornamental brass scrap used which was recommended by (Joel, 2016) as one of the best scrap for jewelry production due to its good mechanical properties. The casting done using the five samples of plaster moulds was to determine the cause of defects resulting from the moulds (A – E). The instruments used for the casting was of less standard, no deoxidizer as a result the pouring rate and temperature of the melt was not monitored. Below are the plates of cast pendant from samples A – E while table 7 show the description of the casts.

Plate of used moulds and cast pendants (Jewelries)

Production obtained from cast samples shows that the defects encountered on sample A, D, and E are pinholes, drop cuts, dirt, dimensional in accuracy, stickiness', mould edge blows rat tail and scabs on the surface of the casting. These could be as a result of the materials additives ratio, which leads to poor porosity, compression strength and density. But samples B and C have less defects which are pinholes on the surface of the castings, little misruns, and correctable dimensional in accuracy were observed. The pinholes could be as a result of combustible contents from the other additives, therefore, the additives such as lime and magnesium oxide as setting time and expansion reduce respectively needs to be investigated. Therefore, sample B and C are suitable for jewelry plaster mould.

Conclusion

Jewelry production as a dynamic discipline, over the years, has undergone revolutionary changes, especially with the technological advancement in foundry. The presence of Jewelry cast products in the society make adornment more meaningful and interesting. The suitability of plaster mould for indigenous jewelry production will help Jewelers find their ways in modern society; in the production of articles such as earrings, bungles, pendants among others, which accomplished buyers' desire and acclimatize with modern technology and will also impact on their economic standard. The evolution of new technology in Jewelry production has found to be more radical and widespread, if it has good potential jewelers who are ready to learn it will help their economic statues.

Expectation is that, the dynamism in the field of professional practice should reflect on the corresponding Jewelers discipline. Consequently, in addition to possessing the skill of plaster mould making techniques for Jewelry production. It is expected that plaster mould would be proficient in jewelry producers.

Recommendations

Due to high rate of unemployment in the country, plaster mould can be a craft for both formal and informal practices, where an individual can specialize in just the mould production or the practical casting for the jewelry producers.

- The ratio formation as in sample A, C and E can be modernize to meet standard for foundry works.
- During casting, deoxidizer should be used to reduce defects.
- Zircon and sodium silicate which are auxiliary moulding materials can be added to strengthen the mould for effective production during casting.

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