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Computer Aided Manufacturing of Sand Casting Products

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Abstract: The research investigates the traditional methods of sand casting processes. It also develops computer software called EASYCAST for manufacturing process of sand casting using computer as an aid. A suitable computer programme was developed to implement the algorithm for the computerization process. A life (two practical) components or products was used to test the validity of the computer software developed. In carrying out this research it was observed that some important facilities to achieve a perfect casting were not available. The manual ways of making pattern and mould which was prominent in the developing world for casting (which was not following the full theory as presented in this research) make the work difficult to achieve. This explains the reason for not reaching the 100% close accurate result to that of EASYCAST Computer Software Manufacturing Model developed in this study which is theory based.

Key words: Computer, manufacturing, sand, casting, products, algorithm

INTRODUCTION

Casting of metals can be traced back to around 4000 B.C. Gold was the first metal to be discovered and used by the early civilizations. It was malleable and could be readily hammered into shape at room temperature. Later, men discovered Copper, a metal much harder than Gold, less malleable and difficult to shape by using the first metallurgical methods. According to some history records the discovery of Clay long before this of Copper brought the idea of making a pattern using pottery stuff, to shape Copper into bowls by casting. Some believe that casting came by accident when reducing Copper ore into useful metal form. Through any of these records or others, Copper Frog is the oldest known casting in existence which was performed in Mesopotamia (present Iraq). The casting technology was spread throughout the world and permitted making of more sophisticated tools and weapons and new and various shape were be made. More detailed implements and ornaments could be fashioned. Fine gold jewellery could be made more beautiful and valuable than by previous methods for any metal could be cast.

Egypt ruled the western civilized world during the Bronze Age (nearly 2000 years) largely due to its ability to perform the casting process. 800 B.C. Chinese were the first to cast iron and performed the earliest known sand Casting 645 B.C.Religion provided and important influence during Dark Ages (circa 400 to (400 A.D.) for perpetuating the foundry man's skills. Construction of cathedrals and churches required the casting of bells that were used in these structures. Indeed, the time and effort needed to cast the large bronze bells of the period helped to move the casting process from the realm of art toward the regiment of technology. Advances in melting and mould-making techniques were made.

Another important product associated with the development of casting was the cannon, chronologically it followed the bell and therefore many casting techniques developed for bell founding were applied to cannon making. The first cast cannon were made in Ghent, Belgium, in the year 1313 by a religious monk, of all people. It was made of bronze and the bore was formed by means of a core during casting. Over the years more processes came to be and old ones were improved and today computer can be used as an aid to ease to lead to better achievements.

This study therefore, aims at looking at the modern way of casting its products using computer as a modern tool.

Computer Aided Design/Manufacturing (CAD/CAM): The application of computers in the design and manufacture of components used in the production of items such as automobiles and jet engines are enormous. CAD is software for creating precise engineering drawings. CAM adds a computer to a machine tool, such as a drill or a lathe. CAM engineers similarly use computer modelling to determine the best overall manufacturing procedures for use in an industrial plant, including the testing and handling of finished products. Engineers use CAD and CAM together to create the design in CAD on one computer and then transmit the design to a second computer that creates the part using CAM (Snyder and Grabowski, 2004; Adejuyigbe, 2002).

Introduction to casting: Casting is a metallurgical process by which a molten metal is poured into a mould cavity and then allowed to solidify in the shape of the mould and

- Casting can be done on metal of very large part and heavy weight (over 100 tons).
- Strength, lightness and good bearing qualities are obtained in casting.
- Physical chemical and mechanical properties are more favourable in cast metals.

Casting is a metallurgical process by which a molten metal is proud into a mould cavity and then allowed to solidify in the shape of the mould cavity after sometimes (Bertoline *et al*., 1995). According to Bertoline *et al*. (1995), Gyasi (1992) and Wynn (2004), advantages and disadvantages of casting are;

Advantages of casting

- Cating processes can be performed on any metal that can be melted.
- Casting ease the shaping of complex geometries compared to other shaping processes.
- Casting is suited for mass production.
- Casting can be done on metal of very large part and heavy weight (over 100 tons).
- Strength, lightness and good bearing qualities are obtained in castings.
- Physical, chemical and mechanical properties are more favourable in cast metals.

Disadvantages of casting: Casting presents some disadvantages for different processes which, for most of them are:

- Limitations on mechanical properties
- Weak porosity
- Poor dimensional accuracy and surface finish for some processes

Chemical hazards when processing hot metals molten which is a threat to the environment.

The gating system is the way or channel through which the molten metal is conveyed to the cavity, it consists of a downsprue or sprue, through which the metal enter into the runner that leads to the mould cavity. At the top of the sprue, a pouring cup is of the used to minimize splash and turbulences as the metal flows into the downsprue and gates.As mentioned before there is a need for taping during process to obtain better finished parts, the following equation gives an approximated amount of taper to be done:

$$A_1/A_2 = (Z_2/Z_1)^{1/2}$$

Where:

A_1 area of sprue entrance 1
A_2 area of sprue base 2
Z_1 depth of metal level in pouring
Z_2 distance from metal level in pouring ba basin to base of sprue.

The Bernoulli's equation is an essential tool to determine the velocities of the molten metal outside and inside the gating system:

$$P_1/\rho + v^2_1/2g + h_1 + F_1 = P_2/\rho + v^2_2/2g + h_2 + F_2$$

Subsequently the height of the sprue, for if we consider frictional forces to be negligible ($F_1 = F_2 = 0$) and take the top of the sprue to be the reference point $h_2 = 0$ and $v_1 = 0$ and assuming that $P_1 = P_2$, the equation reduces to:

$$h_1 = v^2_2/g$$

From the fluid mechanic law of Continuity, which states that: The quantity of fluid flowing per second passing all point in a full channel is the same irrespective of local changes in cross-sectional area and velocity, we can design the top and bottom areas of the sprue:

$$Q = A_1v_1 = A_2\,v_2$$

With

Q: Volumetric flow rate
A_1: Area of the top part of the downsprue
v_1: Velocity at the top part of the downsprue
A_2: Area at the bottom part of the downsprue
v_2: Velocity at the top part of the downsprue

Derived from the first principle of Bernoulli's equation:

$$v = \sqrt{2gh}$$

g is the acceleration of molten metal due to gravity h is the height of the sprue.

Runners and in-gates design: These two parts convey the molten metal from the sprue base into the mould cavity. From research made by Adejuyigbe (2002, 2004), Rao (2001) and http://www.castingsource.com/tech_art_metalcasting.asp areas of in-gates can be calculated by the following expressions involving the dimensions of the sprue:

$$W = KA\sqrt{H}$$

$$\text{And} \quad K = \frac{As}{Ag}$$

Where:

W : Orifice coefficient of the sprue
K : Ratio of sprue and in-gate areas
A : Minimum sprue area
H : Sprue length
As : Sprue area
Ag : In-ate area

Total cross sectional area of the gates is determined by the following expression:

$$Ag = \frac{Mo}{\mu \beta t p \sqrt{Hst}}$$

Where:

Ag : Area of gate in cm^2
Mo : Mass of rough casting
μ : Coefficient of friction
β : Force coefficient dependent on the types of cast alloy
Hst : Effective static head
τ_p : Optimum pouring time

Riser and feeding system: During cooling and solidification phase, the molten metal shrinks. In order to compensate that solidification shrinkage a riser is used to keep excess molten metal after the metal solidifies.

In designing a riser a diameter to height ratio is normally set expressed by:

$$\frac{D}{h} = r$$

$$\text{Hence} \qquad h = \frac{D}{r}$$

Feeding system and design: The gating and feeding system of a mould is essentially the combination of passages and elements of the mould cavity. Feeding system and riser have the same design, which depends on the characteristics of the material used.

The Cain's formula according to Adyuyigbe (2002) and De Garmo (1979) for the relative freezing time, F to be given by:

$$F = \frac{a}{(V - b) + c}$$

Where,

$$F = \frac{\left(\frac{\text{Area}}{\text{Volume}}\right)\text{Casting}}{\left(\frac{\text{Area}}{\text{Volume}}\right)\text{Riser}}$$

$$V = \text{Volume ratio} = \frac{\text{Raser(volume)}}{\text{Casting (volume)}}$$

a = Freezing characteristic constant
b = Liquid solidification contraction
c = Relative freezing rate of riser and casting
a, b and c differ from one metal to another.

For economic reasons, the weight of the feeders must be kept as low as is consistent with the adequate feeding. The Feeding Efficiency (E_f) helps us satisfy this condition.

Volume of mould cavity: According to Heire *et al.* (1994) he said that by knowing the Mould Filling Time (MFT), the volume of the mould cavity can be determined by:

$$MFT = \frac{V}{Q}$$

Where:

MFT : Mould filling time
V : Volume of mould cavity
Q : Volume flow rate of the molten metal.

MATERIALS AND METHODS

The methodology that was adopted in this study is to collect all the necessary data and information from the internet, the use of Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana, library and visitation to available foundry workshop at Kumasi, to identify the main manufacturing process involved in the sand casting and also locate which of the process could be computerized (that is to use Computer-Aided).

A suitable computer programme was developed called EASYCAST to implement the algorithm for the computerization process. The software was test run if it will be suitable for producing a product. A life product was used to test the validity of the computer soft ware developed.

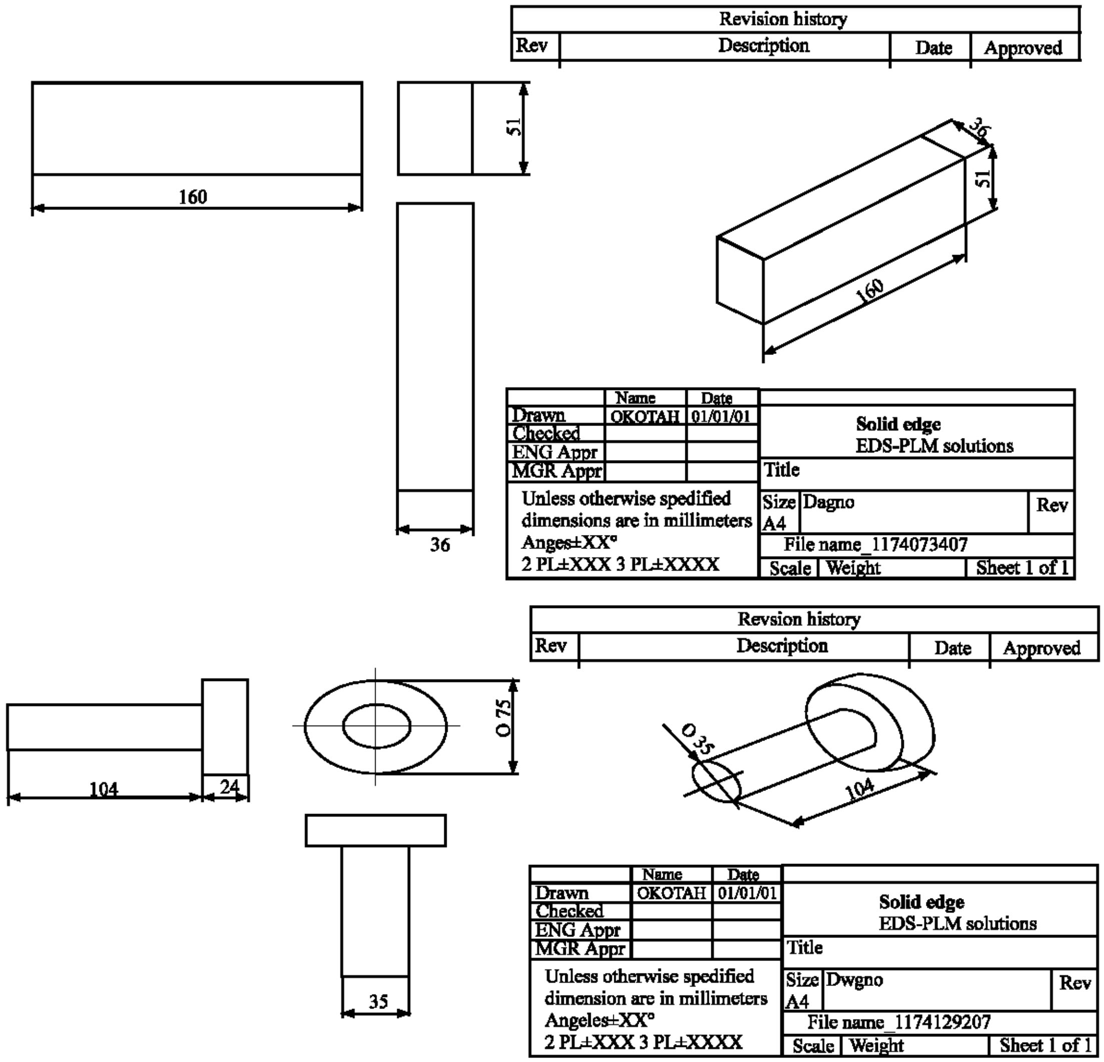


Fig. 1: Components design

This research was carried out at KNUST, Kumasi and Atanga Foundry Works (Suame, Kumasi). Atanga foundry workshop was where the manual casting process was done. It involved the study of the prevailing traditional sand casting process to identify where computer can be used as an aid.

From the literature, the manufacturing process of sand casting method includes the following steps shown:

- Component design
- Pattern making
- Making mould and cores
- Casting (Melting, pouring and cooling)
- Knock out
- Cleaning and checking

Other related and optional steps include; Scrap melting, charging and tapping and pouring, used sand and binding new or retained sand distribution.

Description of the products: Three components are used to illustrate and evaluate the software that will be developed to aid in the sand casting products. Among the objects that will be produced are:

- A cylinder,
- Flange and
- A rectangular block pattern.

To achieve these three casting the research have the following steps:

- Selection of metal of alloy to melt considering properties of that metal so as to produce good products.
- Making detail drawings of object to be cast
- Determining and applying required tolerances for pattern dimensions.
- Performing the casting of the products.
- Establishing a flow chart to direct and control the process.
- Finally coding of software needed for the process with a selected programming language.

Selecting the casting material: A great deal of consideration is given in the selection of the metal required to perform the casting for this project. The criteria for this selection are based on the following;

- Availability;
- Price and workability.

Due to the availability, price and workability of Aluminium and Brass they were chosen for the purpose of our research.

RESULTS

The dimensions and detailed drawing of the products: The dimension of the products to be cast is given in the Table 1. These dimensions would be used to compute the dimensions for the patterns that would be produced to be used for creating the mould cavity.

The drawing for the products are shown in Fig. 1.

Results of process according to the coded software developed: Applying allowances factors to dimensions of objects to cast and following the theory shown in the mould making concerning the melting, pouring and solidification time, EASYCAST presents the following (Fig. 2-10) results as shown in Table 3.

Comprison between actual casting and software: From results observed in the two previous sections, we can observe the following. Table 4 shows the comparison between data from practical work carried out and the software developed.

Table 1: Metal used in the casting and their dimensions

Metal	Alluminium				
Contration Allowance(mm m^{-1})	13				
Machining Allowance(mm m^{-1})	5				
Part	Type of dimension	Actual dimension A/d	Actual dimensions + contraction allowance	A/d+c/a+m/a	Pattern dimensions
Cylinder	Diameter	45	45.585	50.585	50.6
	Length	175	177.275	182.275	182.3
Flange	Diameter 1	68	68.884	73.884	73.9
	Diameter 2	32	32.416	37.416	37.4
	Length 1	103	104.339	109.339	109.3
	Length 2	25	25.325	30.325	30.3
Retangular block	Length	160	162.08	167.08	167.1
	Breath	36	36.468	41.468	41.5
	Height	51	51.663	56.663	56.7

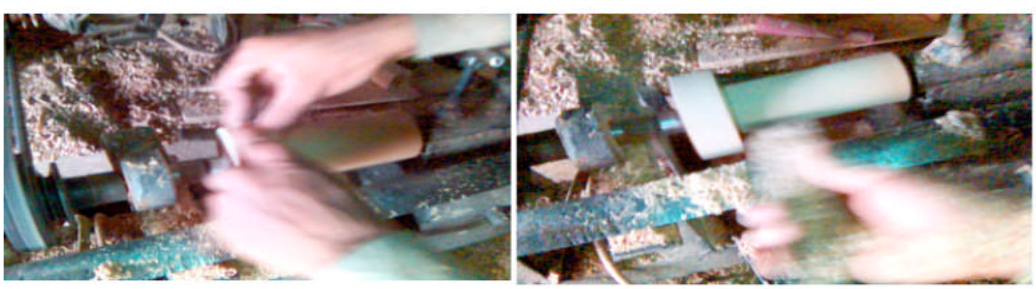
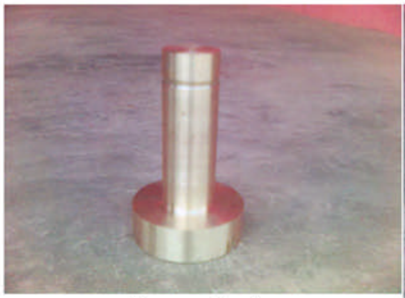


Fig. 2: Pattern production in action

Fig.3: Plates for mould preparation

Fig. 4: Plates of the products after casting before machining



Flang made of

Rectangular block

Cylindrical shaft made

Flang made of

Fig. 5: The finished products after machining

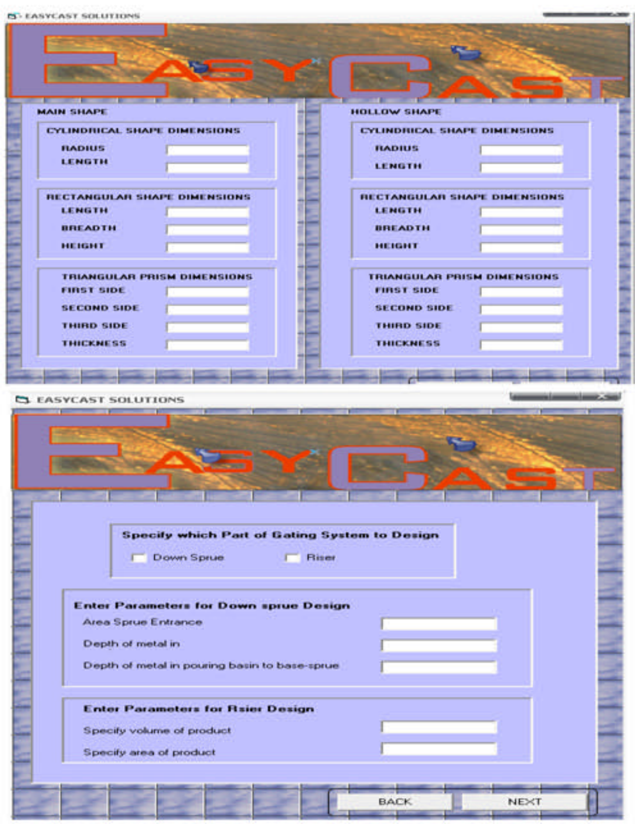


Fig. 6: The programme interface

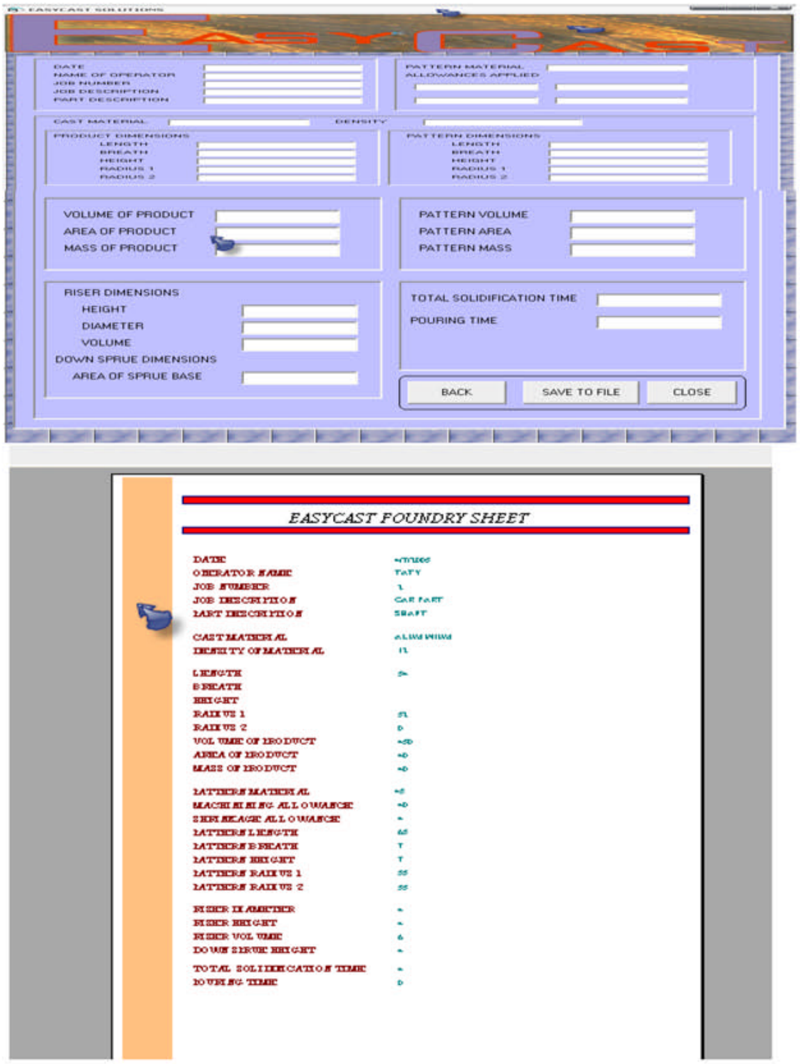


Fig. 7: The programme interface continued

DISCUSSION

Length 1 of the flange made of Brass, the diameter 1 of the flange made of Aluminium and finally the length 1 of Aluminium flange do not present a good accuracy. This is due to the fact that not all conditions were satisfied to achieve perfect casts.

We can also see that the casts present some defects; the properties of metals used were checked to ensure that Aluminium and Brass were homogenous.

We see that the theory applied in EASYCAST follows a perfect and logic sequence of actions which should lead to about 98 % accurate results. But performing casting in Kumasi foundry shop was not as technical as expected since it presented the following problems:

- Designing of mould system known as: Gating and Feeding system was not practicable, since tools required for such and conditions were not favourable
- Melting of metals was done regardless of mathematical formula presented in the literature review.
- Actual pouring and cooling time happen not to match those from EASYCAST.
- The manual casting did not give way to record the exact solidification time.
- Because of cost metals used might not respond to the properties required for the expected results.

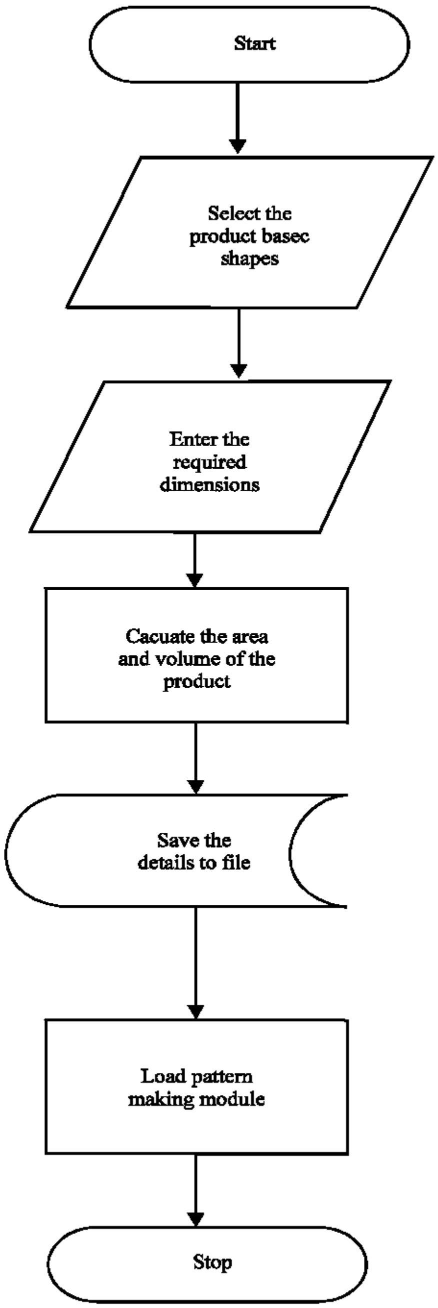


Fig. 8: Component design flow chart

Table 3: Showing output from program

Material	Object	Type of dimension	Values (in mm)
Brass	Flange	Diameter 1	75
		Diameter 2	35
		Length 1	104
		Length 2	24
	Rectangular box	Length	160
		Breath	36
		Height	51
Aluminum	Flange	Diameter 1	68
		Diameter 2	32
		Length 1	103
		Length 2	25
	Cylinder	Diameter	45
		Length	175

Table 3: Continued

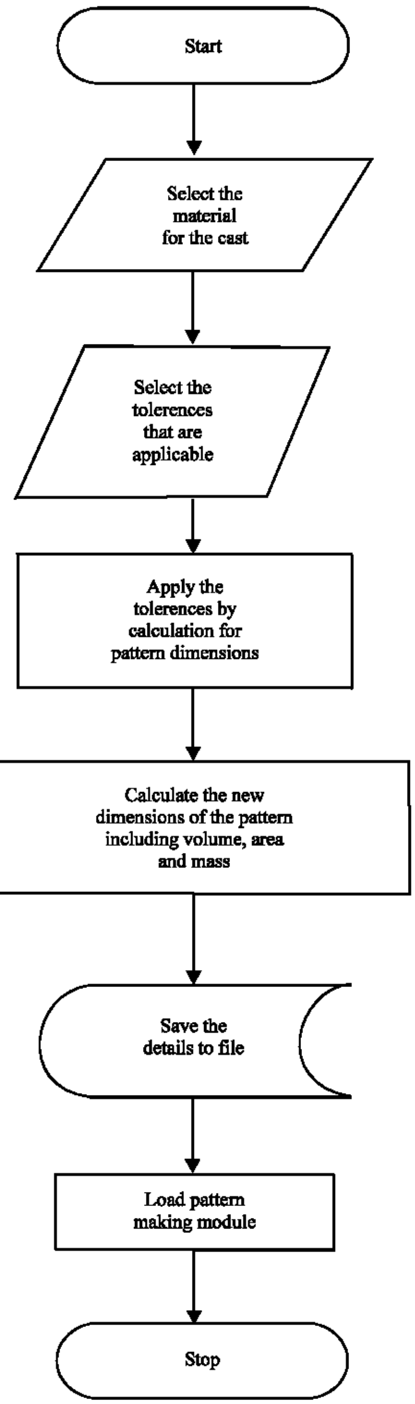


Fig. 9: Pattern making module flow chart

Table 4: Comparison between data from practical and software

Material	Object	Type of dimension	Values from casting (in MM)	Values from software (in MM)
BRASS	Flange	Diameter 1	74.2	75
		Diameter 2	35	35
		Length 1	101.7	104
		Length 2	24	24
	Rectangular box	Length	161.7	160
		Breath	35.5	36
		Height	51	51
Aluminum	Flange	Diameter 1	70	68
		Diameter 2	32	32
		Length 1	96	103
		Length 2	25	25
	Cylinder	Diameter	45.1	45
		Length	175.6	175

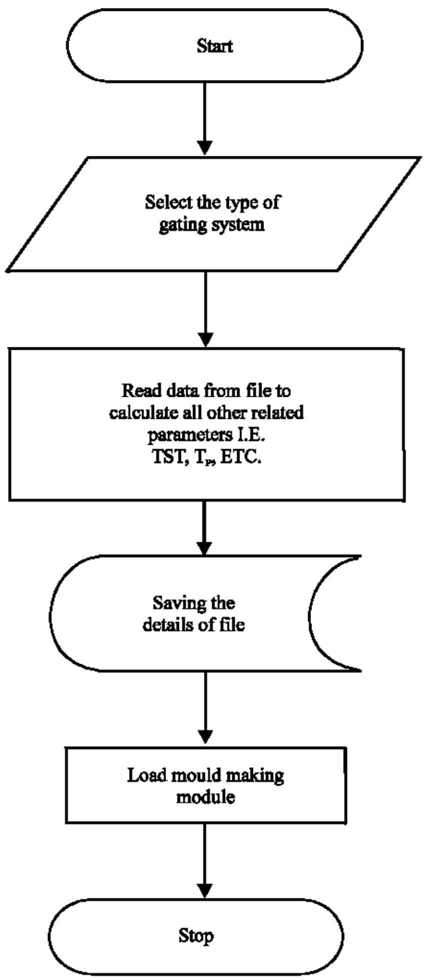


Fig. 10: Mould making module flow chart

- Foundry men were not able to and could not work according to theory.

CONCLUSION

Through the research into theory and practical on the topic of this research the following were clearly identified; the origin of casting and the traditional way of doing sand casting and the use of CAD/CAM systems in today's industry. From theory gathered on sand casting process we identified mathematical relationships that were implemented in programming the software to be used on computer as an aid in the casting process. Easycast was hence written to provide basic relevant analytical information needed by foundry worker who are involved in the traditional sand casting process. Before writing the software, four objects were cast at foundry shop during this process the areas that could be aided by computer were identified and hence the software called Easycast was developed. Data collected during the casting was compared to that generated by the software for the same products to help evaluate the software.

Therefore, this research has succeeded in an attempt to implement CAM in the area of analytical control in the foundry practice suited to the prevailing traditional sand casting process in Ghana. It is therefore, hope that others would also work on similar project to add to and improve on what has been achieved to improve on foundry engineering in African society.

RECOMMENDATIONS

In carrying out this research, it was observed that some important facilities to achieve a perfect casting were not available because the manual ways of making pattern and mould; for performing casting according to the theory was not practicable. It explains the reason for not reaching the accuracy that is close to that of Easycast computer model software developed which is based on theory.

It is therefore, recommended that Engineering of Kwame Nkrumah of University of Science Technology and foundry shops in Kumasi as well as Ghana need to acquire more advanced and qualified tools and equipment to make this computer aided theory practicable. It is believed that breaking the gap between theory and manual casting will lead to better results.

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