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Effect of the Mould Rotational Speed on the Quality of Bimetallic Pipe Fabricated by Centrifugal Casting Process

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Abstract—

Bimetallic pipes have found a wide range of applications in the present market scenario. It is due to the fact that they possess really impressive mechanical properties like high corrosion resistance at elevated temperatures, high strength, high toughness, etc. The bimetal pipes can be made by using several combinations of metals depending on the requirements like Al-Cu, Al-Ni, etc. Bimetallic pipes are manufactured by the principle of cladding where one metal is made to clad over another one. They have found their applications in steam condenser, heat exchangers, water supply, industrial applications, etc. These pipes are manufactured using the centrifugal casting process. This paper deals with the effect of the various mould rotational speeds on the quality of the bond produced in the Al-Cu bimetallic pipe while fabricating through the centrifugal casting process. The vertical centrifugal casting setup is used for the process. The detailed analysis of the bond quality is done using Scanning Electron Microscope (SEM). Furthermore, the chemical composition of the bond is studied by using Energy Dispersive X-Ray Spectroscopy (EDS). The strength and quality of the Al-Cu bimetallic bond is studied at varying rotational speeds of the mould and finally the observations are taken. The conclusion is framed accordingly based on the observations.

***Keywords**:Al-Cubimetallic pipe, Vertical centrifugal casting, Energy Dispersive X-Ray Spectroscopy (EDS), Scanning Electron Microscope (SEM), Cladding.*

I. INTRODUCTION

In today's global competitive environment clad metal materials have become increasingly popular by industrial application such as Al/Cu, Cu/Sus, Cu/Ag, AL/Ni, steel/Ti etc. Among all these Al/Cu bimetals widely used due to its better mechanical property and corrosion resistance. Al/Cu bimetal is nothing but a combination of two metal layers that is Al and Cu which form a metallurgical bonding between them and constitute a single piece. In high direct-current bus system, metallurgical bonding Al to Cu is widely as a transition piece. Because of high diffusion affinity to each other at temperature above 120℃ Al and Cu are incompatible metal that result in the formation of intermetallic compounds, that are brittle and with high electric resistance on their interfaces. Nowadays Aluminum is widely used in industrial application as casting product due to having some special physical property. In our earth's crust, the most abundant element is Aluminum after oxygen and silicon. It is widely used because of its easy availability, good strength resistance to corrosion, less density (2.7 gm/cm3), low Copper is the oldest material which is used in the most of the industrial application and constitute one of the major groups of commercial metals. It is widely used because of its excellent thermal and electrical conductivities, outstanding wear and resistance to corrosion, has good strength and fatigue resistance. Pure copper is extensively used for wires and cables, electrical contacts and a wide variety of other parts that are required to pass electrical currents. Copper is three time heavier than Aluminum with 1083℃ melting temperature and 8900 kg/m3 density. Copper is face center cubic. Melting point (1218 F/ 659℃), low cost, less weight and high resistance to weight ratio. In bimetallic pipe fabrication, the most important thing is metallurgical interface between two metals i.e. in between Al and Cu. Compatibility properties of metal component like specific heat, thermal expansion, thermal conductivity, melting point, phase transformation zone, wettability and reactivity to each other are major factors which affecting the production of bimetal casting product. All of these factors determine bond quality between two metals specially wettability and reactivity. In metallurgical industries, centrifugal casting is widely used as one of the advanced casting technique. It is a liquid phase process. Centrifugal casting machine is made of a high-speed motor, joint with a suitable sample holder which is capable of rotation around the same axis of motor. Centrifugal casting is a process of casting by causing molten metal to solidify in rotating mould. In which the rate of pouring metal and speed of rotation is vary with the casting material and its size and shape that is being cast. The essential feature of the centrifugal casting is the introduction of liquid metal into a rotating mold. Centrifugal force plays major role in shaping and feeding of the casting. There are process variables like pouring temperature, speed of rotation, mould temp, pouring rate in the way of processing of composite material that are needed to take into consideration while processing through centrifugal casting, and their effects on the properties of composite materials. These helps in reducing the defect in casting product and enhance the mechanical property of composite cast product.

A. Mould wall thickness

Mould wall thickness is an important parameter of centrifugal casting. Metal is pressed toward the inner wall of mould by centrifugal force. Mould wall thickness affect the microstructure of casting product, as solidification process depend

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upon the mould wall thickness. On increasing the mould wall thickness solidification is done at faster rate because the chilling effect of mould and it also decreases the solidification time. For fine grains, casting is produced in thick walled mould and for coarse grains, casting is produced in thin walled mould.

B. Speed of rotation
Speed of rotation of die is an important parameter of centrifugal casting. Molten metal solidifies in rotating mould so the speed of rotation directly affects the solidification rate and indirectly the melt distributions on the wall of mould. Due to this microstructure and mechanical property of casting product also get affected by the speed of rotation. By increasing the rotational speed, centrifugal force also gets increased by square proportion. For avoiding the slipping of melt inside the mould, rotation speed should be as adjusted so that centrifugal force is balanced by gravitational force due to the weight of liquid.

$\text{Centrifugal force on rotating body} = \text{mv2/r}$
$\text{Gravitational force} = \text{mg}$
Where, m: mass of the body (kg)
v: peripheral speed (m/s)
r: radius of rotation (m)
g: acceleration due to gravity (m/s2)
G − Factor is defined as:

$$\text{G factor} = \frac{\text{Centrifugal force}}{\text{Gravitational force}}$$
$$= \text{mv2/rmg}$$
$$= \text{gv2/r}$$
$$= \{\text{g}(3.14 \times \text{r} \times \text{N})2\}/30\text{r}$$

Where N = rotational speed in rpm

$\text{N} = 42.3\sqrt{\text{G}} - \text{factor/2r}$.[1]

C. Pouring speed and pouring rate
Pouring rate is one of the important process parameter of centrifugal casting. By low pouring rate solidification and feeding are promoted and it reduces the risk of tearing. By high pouring rate risk of shrinkage cavity formation is reduced near the bore and also at the outer surface cold shuts and laps is reduced.

D. Pouring temperature and mould temperature
It is the process parameter of centrifugal casting method. In centrifugal casting process, the main function of mould temperature and pouring temperature is freezing time of molten metal. Speed of rotational die does not have any effect on freezing time.

II. LITERATURE REVIEW
There is research paper are available on the effect of the mould rotational speed on the quality of bimetallic pipe fabricated by centrifugal casting process some of them listed[2]who definedcasting as a “metal object obtained by alloying molten metal to solidify in a mold” the shape of the object being determined by the shape of the mold cavity. Casting is a manufacturing process of metal, metal matrix composite, bimetal or non-metal also, in industries. In this method the liquid metal is generally poured into mould, which contain a hollow cavity of desired shape then solidify in it. The solidified part is known as casting product. There are various type of casting method, but in this research work mainly focus on centrifugal casting process due to commonly used and having successful result regarding less defect, fine micro-structure and improved mechanical property.In metallurgical industries, centrifugal casting is widely used as one of the advanced casting technique. It is a liquid phase process. Centrifugal casting machine is made of a high-speed motor, joint with a suitable sample holder which is capable of rotation around the same axis of motor.[3]statedthatcentrifugal casting is a process of casting by causing molten metal to solidify in rotating mould. In which the rate of pouring metal and speed of rotation is vary with the casting material and its size and shape that is being cast. The essential feature of the centrifugal casting is the introduction of liquid metal into a rotating mold. Centrifugal force plays major role in shaping and feeding of the casting.[4]stated that in centrifugal casting process, it is almost impossible to observe the melt behaviour of the casting as the centrifugal casting process is a very fast process with melt, cast and moulds being opaque.

The present paper is regarding the horizontal transparent moulds and transparent fluids with different viscosities by cold modelling experiment to study the effect of the different variables on the flow patterns. Apart from the production of a complete hollow fluid cylinder, the present paper investigated the effect of the thickness of the fluid cylinder, viscosity of the fluids and the diameter of the mould on it. In this experiment, the cylinder was cast at different speed with varying the mould wall thickness and it was observed that the hardness of the casted cylinder was increased with increasing the rotational speed. Different flows like Couette flow, Ekman flow and Taylor flow were observed by a cold modelling experiment, before a good fluid cylinder formed. Among all these flow at lower aspect ratio, Ekman flow disturb the fluid flow but its effect become negligible when the aspect ratio is increased. For 4 and 6mm mould wall thickness, all type of flow will be prevalent to leading casting with irregular inner surface at lower rotational speed. When the speed is increased all type of disturbance was avoided and liquid metal form a full uniform liquid cylinder. It was also observed from the experiment that in the formation of liquid cylinder viscosity plays a vital role. At low viscosity, the rotational speed is high for the formation of liquid cylinder whereas at high viscosity, the rotational speed is slow. [5]intheirresearch focussed on the effect of the mould rotational speed on the quality of the centrifugal casting process. Hollow casting was done as the centrifugal force lift the molten metal or alloy which is poured into the mould along the inner surface of it. From this experiment, it is clear that in centrifugal casting process, the rotational speed of the die is one of the process variable that not only effect the flow pattern inside the mould of the melt but also the casting dimension uniformity and consistency that are being casted i.e. it indirectly effects the micro-structure and mechanical properties of the casting. It was found from the experiment that uniform cylinder is casted at critical speed 1300 rpm. And metal disturbs its position at speed below and above the critical speed. The critical speed is also known as optimized speed because at this speed i.e. 1300 rpm the mechanical properties of casting was found to be improved which was mainly because of the way molten metal flow inside the mould.[6] stated that inn centrifugal casting process, the micro-structure, quality, and material properties of casting is highly affected by the rate of solidification but due to rapid solidification, rotating mould, high pouring temperature and opaque mould, the analysis of heat transfer is very complex in centrifugal casting process. In casting, the rate of solidification is depends upon the grain size. In this experiment, firstly gravity casting was done at different cooling rate cooling rate 1, cooling rate 2, cooling rate 3 with wall thickness of 10mm, 20 mm and 30 mm. For the above three cases, cooling curve was drawn in this experiment and the slope of these curve represent the rate of solidification. After that centrifugal casting process was done with the different rate of solidification which is achieved by the gravity casting process, where the speed of rotational mould was varied from 0 to 2000 rpm. It was actually done at three different speed 200 rpm, 400 rpm and 800 rpm. From the result of this experiment it is shown the coarse grains was found at slow rate of solidification and equiaxed grains at faster rate of solidification. It was also investigated that the rate of solidification is faster at around 400 rpm speed of rotational mould and due to this fine grain microstructure was formed. And at around 800 rpm the rate of solidification is slightly slow and due to this coarse grain are formed.[7]stated that in centrifugal casting process virtue of the centrifugal force, the molten metal occupies into the cavity. In this paper, the experiment set up of horizontal centrifugal casting process was designed for the production of cylindrical components. This experiment set up consist of a cylindrical mould of stainless steel which is fixed by a driving flange on the both side. With the help of nut and bolt, the mould is connected in temporary manner by driving flange. In this experiment, the molten metal was of lead because of its low melting point and the DC motor was varied up to 1400 rpm. For the modelling of centrifugal casting process, the numerical simulation was carried out with the help of ABAQUS program. The main merit of this project is to produce defect less cast product with different parameter of horizontal centrifugal casting process. It was shown from centrifugal cast sample that cast product has a fine coarse microstructure from outer to inner surface. The final cast was affected by solidification process and the directly measurement of the rate of the solidification of casting is highly impossible but it can be determined by the grain size. Coarse grains were observed when the solidification rate was slow and at high solidification rate it shows a fine equiaxed grains. The rate of solidification was faster at around 400 rpm because of turbulence and due to this a fine grain micro structure was formed. At around 800 rpm the rate of solidification is slightly slower and form a coarse grains microstructure.[8]stated that in centrifugal casting process defect will occur on resultant casting product because may be of single cause or may be due to the presence of some more causes which is related to foundry shop and its resources available. In casting process, the defect which is generated is very intuitive in nature. And it’s become roots which cause it, is not probably identified by foundry men but it can be identified if a deep scrutiny of defect is done. The defect can be found with the input variants which can be changed considerably.[9]fabricated (Al-Si) 4600 Aluminum alloy through the centrifugal casting process and then investigated the influence of process parameter on its micro-structure and mechanical properties and applied Taguchi method for optimizing the process parameter and to reduce the defects which leads to increase the mechanical properties of the cast alloy. Investigated that increase in pouring temperature reduces the mechanical property while increase in die speed increase the mechanical properties and densities. So, for fine grains in matrix, pouring temperature should be low while the speed of the die should be high. In this process ANOVA techniques used they analyzed the result to know the percentage contribution of each process parameter. Also analyzed the microstructure which indicates that Al concentration is more at the outer periphery[10] performed Optimization of the casting defect using computer aided casting simulation software. By using this software provide proper runner and gating system which is very important to secure good quality of casting and also it provides a homogenous mould filling pattern. To eliminate the premature freezing of the molten metal, they added more overflow entrances at the end of the cavity. From this experiment, they found that computer aided casting software technique is the most efficient and accurate method for analyzing defect like weld lines, air traps and shrinkage. By this technique, quality and yield of the casting were improved in the shortest possible time and without carrying out the actual trash on the foundry shop floor[11]fabricated thebimetallic roll by the method of centrifugal casting with rotation of mould around the horizontal axis. Experimentally found the hardest, micro-structure and residual stress. Also simulate the whole process using Pro-cast software and found that the compressive tangential stress found at the outer periphery due to this corrosion effect was reduced and fatigue life was increased. Investigated from a mould that compressive radial stress was near the interface of the two metals and it helped in reducing the tendency of separation. The stress was obtained by numerical solution method and compared with the residual stress at six measured locations. It can be reduced by cooling the casting inside the mould. Also investigated about the pouring time and found that the earlier the liner layer is poured, the less are the residual stress. Residual stress can be increased by increasing the mould speed. Found that cooling with result in smaller residual stresses. [12]investigatedon the basis of numerical simulation and experimental procedure to analyse the defects in casting of Ti-6Al-4V alloy by vertical centrifugal casting process on graphite mould. This experiment was done at different-different vertical centrifugal casting conditions. From this experiment found that this method was most suitable for reducing the defect severity. When the mould rotation increases from 0 to 210 RPM, the numerical percentage of defect-visible-specimens start decreasing from 62.4% to 24.8%. When the gravitational coefficient was increased, the quantity of macro pore defects starts decreasing exponentially. But it starts increasing when the mould rotating ratio decreased. More defect is caused when casting was made earlier and longer mould filling path because more inclusions and gas pore will be easily entrapped in alloy melt. So that mould filling process is also influenced the casting process.[13]research work implementedthe Taguchi design of experiments for optimization of manufacture of sintered one step alumina micro filter/membrane fabricated by the centrifugal casting method for the first time. In its 10 out. % alumina aqueous slip containing T iron (0.001 g/g alumina) as dispersion and PVA as a binder was used. For controlling parameter, they selected 3 level accelerations, 3 level slip volumes, 3 level binder content and 2 levels PH. They discussed three target function (i) the product of the top layer porosity time (ii) product of permeability times thickness (iii) membrane curvature. From the overall experiment, they found that (i) fir improving the centrifugal processing route for the membrane support manufacture Taguchi method was most appropriate method (ii) a major membrane supper characteristic is the product of surface porosity x which is reciprocal of surface average pore diameter. [14]performed the analysis of the Taguchi method to find the pipe thickness of IS-3989 cast iron pipe which fabricated through the centrifugal casting process. In this experiment controlled the various parameters like pouring temperature, mould spinning speed and coolant flow rate. Proceed this experiment by ANOVA analysis and found the optimum parameter (i) pouring temperature = 1325℃(ii) mould spinning speed= 1000 RPM (iii) coolant flow rate= 15 lit/min and other contributions of other parameter are (i) mould spinning speed 54.336% (ii) pour temperature 30.133% and (iii) coolant flow rate is 10.556%.[15] Fabricated a model of centrifugal casting wet-type cylinder liner based on Pro-cast simulation software to reduce the defects in the wet type cylinder liner such as micro-segregation and shrinkage holes etc. The pro-cast software for analysis of the flow behavior of the metallic melt during horizontal centrifugal process. It also simulates the mould filling and temperature field of the casting process. After that, they compared the temperature field simulation result and defect which occurs in the actual casting process. From this found that the Pro-cast software is the most suitable for horizontal centrifugal casting process. Also calculated the water cooling starting time, difference in mould wall thickness, the thickness of thermal wall insulation materials and the difference of coating thickness of the defect area with the help of temp field obtained by Pro-cast. And found that the improved solution for actual casting process which is as (i) difference in mould wall thickness= 16 mm (ii) thickness of internal insulation material=2 mm (iii) difference in coating thickness= 1mm (iv) timing of cooling=20 Sec (v) water cooling=70 Sec (vi) air cooling =20 Sec. Casting done using this data produces less defects in WTCL.

III. EXPERIMENTATION

The bimetallic pipes are manufactured by the principle called as cladding. Cladding deals with the concept that a metal is made to clad or cover over another metal which will just act as an insulation covering over a metallic body. In order to ensure proper cladding a strong bond formation need to take place. The process of formation of a bimetallic pipe can be accomplished by adopting the vertical centrifugal process at three different rotational speeds. The varying rotational speed taken are 800 rpm, 1320 rpm and 1980 rpm respectively. The Aluminum and Copper are first of all heated to their respective Melting point temperatures. Meanwhile the vertical centrifugal casting machine setup is made ready by preheating the mould and pouring basin to 220°C. The pouring basin coating is done with graphite. It is done to prevent sticking of the molten metal to the pouring basin. First of all, the molten Copper is poured into the rotating mould. Due to the centrifugal action of the mould the molten Copper gets deposited in the walls of the mould forming a layer which solidifies instantly. The molten Aluminum is poured into the same after the outer Copper layer is in semisolid state. It is done so to initialize a good bonding between the Copper and Aluminum as a result of which proper cladding will take place. After the complete solidification of the Aluminum and Copper the bimetal is finally prepared. The main challenges that is faced while executing this process is the pouring of the molten Aluminum right in the time when the Copper is in the semisolid state. It is so because the copper solidifies instantly at a very fast rate. After the formation of the bimetal the sample is sent to for testing using optical microscope and SEM type electron microscope for determining the intermetallic phases at the interface and the width of the phases. It can also use for determining whether the boundary is single or poly structured. Fig.1 shows a vertical centrifugal casting setup which is used to prepare bimetallic pipe.

Fig.1. Experimental setup of Vertical centrifugal casting.

A method of producing a bimetal pipe comprises of the following steps –

- Arranging the mould with its major axis vertical and rotating the mould about the axis.
- Due to the reason of instant solidification of Copper metal, the outer layer (Cu) is directly pour from the furnace into the rotating mould to centrifugally cast an outer layer of copper metal.
- Continuing the rotation of that mould until all but the last portion of the poured metal is solidified, immediately after this mould is filled with the second metal (Al) that make the bond between filled or poured metals.

Table.1 shows the details about the various rotational speeds that are undertaken to produce this Cu/ Al bimetallic pipe. Fig.2 and Fig.3 Shows the pouring of the molten copper and aluminum while executing the process at the shop floor. Fig.4 shows the three different samples that is manufactured by varying the rotational speeds of the mould.

Table 1 material selection and Experimental parameters

SAMPLE	Element	Rotation Speed (rpm)
S1	Aluminium-Copper	800 rpm
S2	Aluminium-Copper	1320 rpm
S3	Aluminium-Copper	1980 rpm

Fig.2.Pouring of Molten Copper

Fig.3. Pouring of molten Aluminum

Fig.4. Bimetallic pipe Samples prepared for testing (a) S1 by 800 rpm (b) S2 by 1320 rpm and (c) S3 by 1980 rpm.

IV. RESULT AND DISCUSSION

As we know that the Vertical Centrifugal Casting Machine is designed for the mould to rotate at different speeds. The “V” belt drive attachment is used to change the speed. In this research three different speeds i.e. 800 rpm, 1320 rpm and 1980 rpm is used for rotating the mould in order to fabricate the Al-Cu bimetallic pipe. The speed can be changed by changing the belt of the pulley which is connected to the driver and motor pulley. The rotation of the mould helps to generate centrifugal force which acts on the metal and solidifies it within the mould. The Fig.4. Shows the product that are casted on this setup at different speeds showing the quality of interfacial bond and microstructure between the Al and Cu in the bimetallic pipe.

After performing the experiment, it is found that 1320 rpm is the most suitable rpm for the good quality bimetallic pipe casting. The difference was observed in the microstructure and the interfacial bonding at other speeds when analysed through the Scanning Electron Microscope (SEM). After the fabrication and scanning of the Al-Cu Bimetallic

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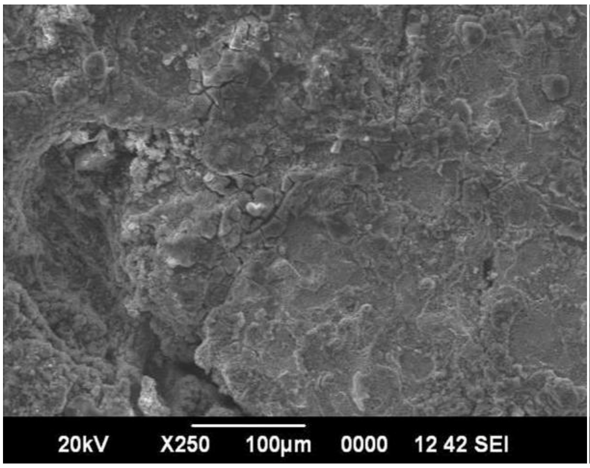
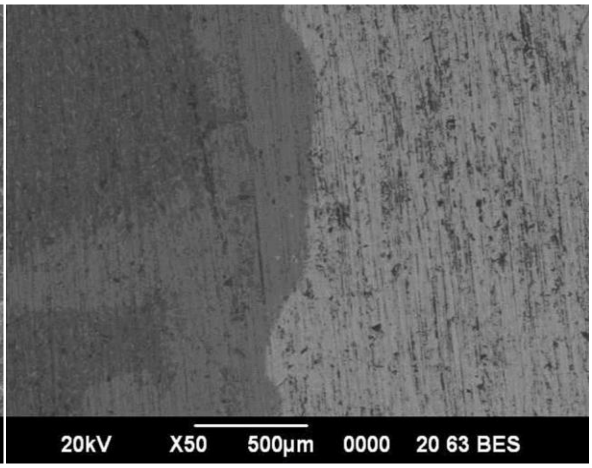
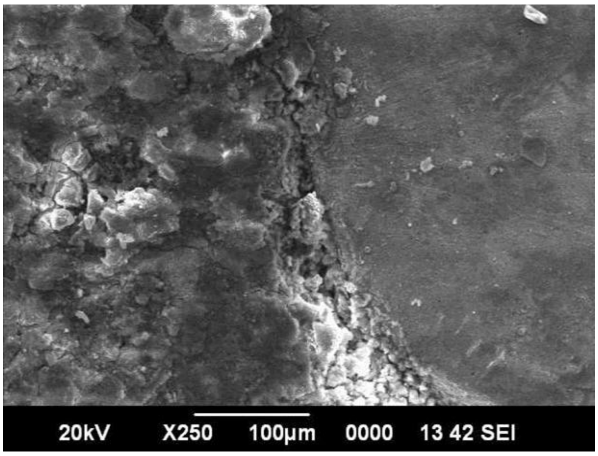
Pipe, the study was undertaken with the help of Energy Dispersive X-Ray Spectroscopy (EDS) to observe the chemical composition of it. And also after all this the optical microscope was used to determine the bonding percentage of Al-Cu bimetallic pipe.





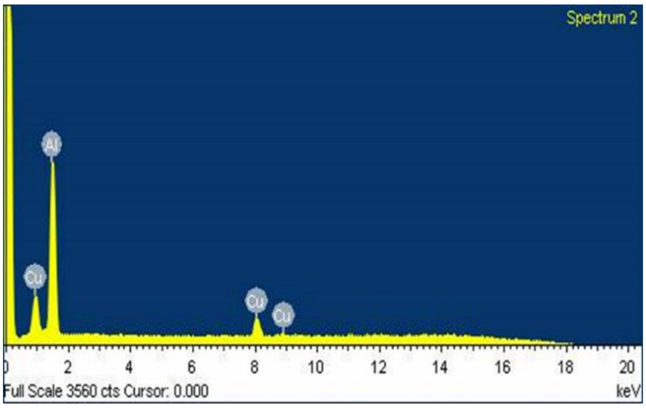
S1 S2

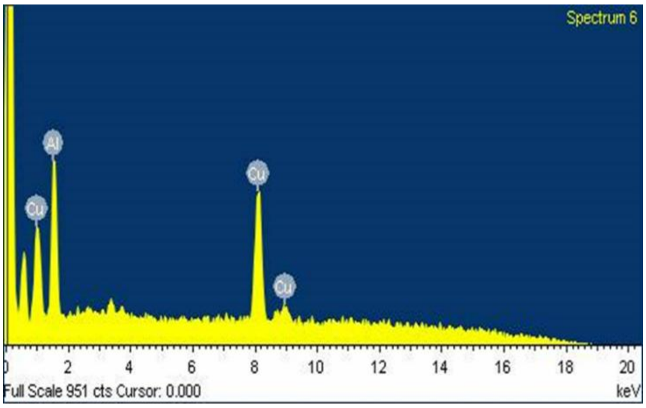


S3

Fig.5. SEM image of Al-Cu Bimetallic pipe fabricated at 800, 1320, 1980 rpm the samples S1, S2 and S3 are formed respectively.

With the help of electron microscope, the intermetallic phase at interface and width of this phase is analyzed as referred to in Fig.5. According to SEM analysis the sample was photographed at required magnification at back scattered mode (BSE). It is found that the boundary survey between the two metals in casted bimetal sample S2 which is fabricated through vertical centrifugal machine at 1320 rpm is quite better rather than the casted bimetal pipe at different rpms such as 800 and 1980 rpm. Here in experimental work, it was observed that the bonding of this boundary type was a result of interphase, intermolecular, intermetallic compounds attraction and repulsion forces. The strength of this type of bonding depend on forces existing between bimetal phases. In most cases, intermetallic compounds create new phases at meeting phase of the bimetal which are brittle and low strength in nature. In this type of bimetallic phases, the intermetallic bonding and attraction and repulsion atomic forces reach to its minimum mechanical, physical and chemical properties of bimetallic phase which is completely different as compared to the two metal properties separately.





[A] [B]

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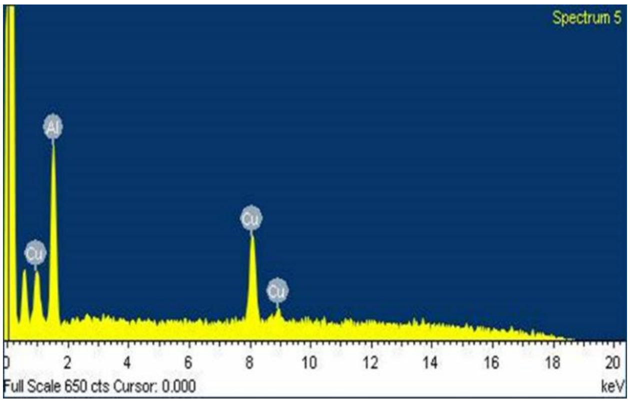
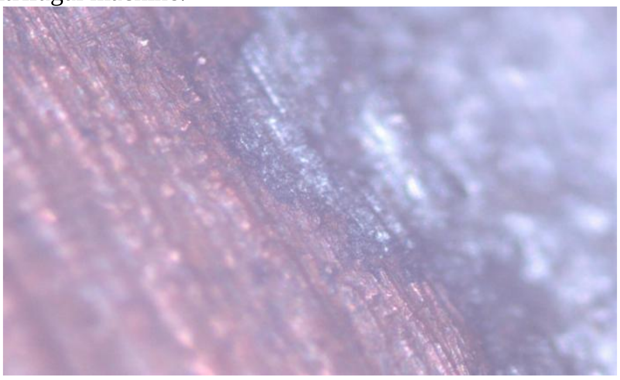


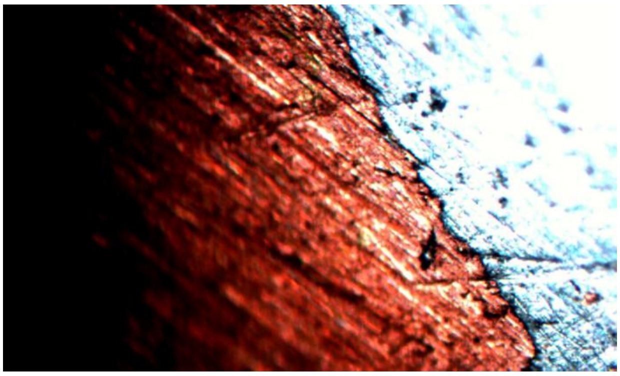
[C]

Fig.6. EDS report of the Al-Cu Bimetallic pipe fabricated at 800, 1320, 1980 rpm A, B and C respectively

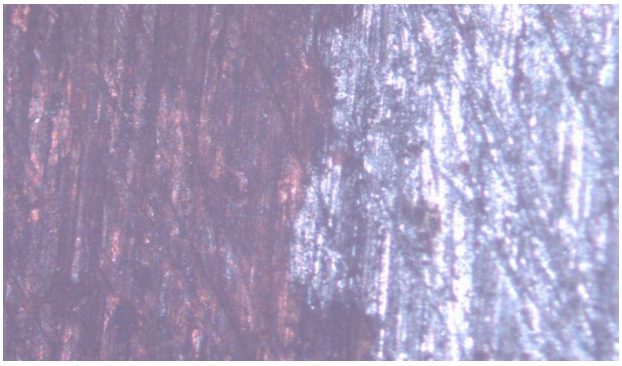
As stated earlier the EDS is used to study the chemical composition between the two metals. Hence, in this research the elemental presence at the bimetallic phase of Al-Cu is studied. According to the Fig.6 A, B and C respectively, it can be concluded that the bonding and the elemental presence is quite better in fabricated at 1320 rpm through vertical centrifugal machine.



[A]



[B]



[C]

Fig.7. Optical Microscopic image of Aluminum-Copper bimetallic pipe fabricated at 800, 1320, 1980 rpm A, B and C respectively.

As referred to in Fig.7. Optical microscope is done for observing the interfacial bond of the casted bimetallic Al-Cu pipe. The observed image reveals the bonding interface is found to be good at 1320 rpm. It reveals that the bonding at two interfaces was quite good as compared to the other rpms such as 800, and, 1980 rpm.

V. CONCLUSIONS

The centrifugal casting experiment to fabricate a bimetal using Aluminum and Copper is done and following conclusions are drawn.

- A Bimetallic pipe of Aluminum and Copper can be cast using the vertical centrifugal casting method.
- Casting defects as gas porosity, shrinkage defect and pouring metal defect are the important factors influencing the cast product and can be avoided if some factors as mold preheating, controlled pouring of metals, rotation speed and solidification time of metals are taken care of.
- Pouring temperature of metals and rotation speed also influence the bonding of metals at the interface and 1320 rpm speed and 700ºc for Aluminum and 1250ºc for Copper can give a good bonding percentage.

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- Effective parameters on the creation of metallurgical bonding between two metals in centrifugal casting were evaluated among different parameters specified temperature for the first metal and then pouring second metal creates a metallurgical bond with proper quality.
- If the temperature is too high the intermetallic compounds create at interface between two metals and if the temperature is too low metal oxides glues and cool the second melt and doesn't quiet the surface of two metal and no bond is formed.
- It was found during evaluation of Aluminum-Copper cast product that in interface shrinkage voids, metal oxides and pure metal bonding region exist, therefore for creating appropriate metallurgical bonds between Aluminum-Copper in vertical centrifugal casting the surface of Copper should be clean without oxides, and also formed in an oxygen free environment

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