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Twin-Roll Casting of Particulate Reinforced Aluminum Metal Matrix Composites a study on Mechanical Properties

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Abstract: *In the current research work, Al6061 reinforced with SiC/Al_2O_3 particles of various configurations has been processed by adopting the stirred casting technique. Energy dispersive spectrometer tests have authenticated that the processed compounds are made up of Al6061 and SiC/Al_2O_3 hybrid composites. The composition of SiC/Al_2O_3 has been used in varied concentration of 0, 2, 4, 6 and 8% by weight and added to Al6061. An optical microscopy study has been carried out to identify the configuration of the composite material. In this study, we have attempted to examine the microstructures and thermal behavior of SiC/Al_2O_3 -reinforced composites with different weight fractions. The microstructure, thermal conductivity, and coefficient of thermal expansion were also examined after adding SiC/Al_2O_3 to Al6061. Al6061 reinforced with SiC/Al_2O_3 particles exhibited better thermal properties than without SiC/Al_2O_3reinforcement*

Keywords: Al6061; SiC/Al_2O_3; Mechanical properties

I. INTRODUCTION

One of the major consumers of wrought aluminum products is automotive industry where weight reduction is a primary goal. The major barrier to the widespread use of aluminum sheets in high volume is it's high cost of production. Aluminum alloys as metal matrix have always attracted material scientists because additional attributes such as better corrosion resistance and high damping capacity. Main aim of developing metal matrix composites is to achieve desired properties by varying matrix phase, reinforcement shape and size, synthesis route, volume fraction and processing parameters. The aluminum alloy strip is usually made from slab by scrapping, homogenization, hot rollings and cold rollings. The strips are connected after cleaning by hot rolling. Process saving is desired at the production of the clad strip for the energy saving. The twin roll caster can cast strip from molten metal directly. Therefore, the clad strip may be fabricated with low energy by the twin roll caster. Because of the economics and metallurgical advantages offered by twin-roll casting (TRC) process, it has become widely popular in aluminum industries [1-8]. This process provides better control over the microstructure and mechanical properties of the cast strip. The twin-roll strip casting process is very simple, but there are several complex phenomena like fluid flow, heat transfer, and solidification involved in the process. The process of twin-roll strip casting is dynamic and quick and occurs at high temperature. The success of twin-roll strip casting process has led to the elimination of the hot rolling process and made the manufacturing of strips, which are difficult to hot-roll [9-15].

II. Al AS BASE MATERIAL

The families of aluminum alloys are represented by 1XXX, 2XXX, 3XXX up to 8XXX. The 1xxx series designation concerns unalloyed aluminum materials which are distinguished according to their degree of purity. The 8xxx series designations are for miscellaneous types of alloys (i.e. Fe alloys) which cannot be grouped in the other families. The 2xxx, 6xxx and 7xxx series are heat-treatable alloys, which gain their strength by alloying but make use of precipitation hardening as the main mechanism. The first digit gives basic information about the principal alloying elements. The designation system also says something about the hardening of the alloys belonging to a family (R. Gitter 2008). The nominal composition Wt% of Al-6061 matrix material (J.Jenix Rino, et al (2012) and K.M. Shorowordi et al (2013)). The 1xxx, 3xxx and 5xxx series are so called non-heat-treatable alloys; they gain their strength by alloying (e.g. increasing content of Mg) and work hardening. Among them Al6061 alloy is highly corrosion resistant, extricable in nature and exhibits moderate strength. It finds vast applications in the fields of construction, automotive and marine fields. They have been studied extensively because of their technological importance and their exceptional increase in strength obtained by precipitation hardening [16-20].

III. REINFORCEMENTS IN ALUMINIUMMATRIX COMPOSITES (AMCS)

3.1 Silicon carbide (SiC)

SiC can be used as reinforcement in the form of particulates, whiskers or fibers to improve the properties of the composite. When embedded in metal matrix composites SiC certainly improves the overall strength of the composite along with corrosion and wear resistance. Aluminum MMCs reinforced with SiC particles have up to 20% improvement in yield strength, lower coefficient of thermal expansion, higher modulus of elasticity and more wear resistance than the corresponding un-reinforced matrix alloy systems. Silicon carbide as such, because of its high hardness, has got a number of applications such as in cutting tools, jewellery, automobile parts, electronic circuits, structural materials, nuclear fuel particles, etc. For these reasons SiC-particulate-reinforced aluminum composites have found many applications such as brake discs, bicycle frames, aerospace and automotive industry (A.K. Vasudevan et al 1995 and B. Roebuck 1987) [A].

3.2 Alumina Oxide (Al2O3)

Aluminum oxide, commonly referred to as alumina, possesses strong ionic inter atomic bonding giving rise to its desirable material characteristics. It can exist in several crystalline phases which all revert to the most stable hexagonal alpha phase at elevated temperatures. It's high hardness, excellent dielectric properties, refractoriness and good thermal properties make it the material of choice for a wide range of applications. Presence of Al_2O_3 particles leads to improve the corrosion resistance of the joint when compared to that of welded joint without reinforcements. The commonly-used Al_2O_3 is produced through the Bayer process starting from bauxite, which mainly consists of hydrated aluminum. In the Bayer process, crushed bauxite is treated with caustic aluminate solution containing soda. The dissolution reaction is generally carried out under pressure at temperatures ranging from 140 to 280°C. The caustic solution reacts with the aluminum hydroxide so that the impurities can be separated by sedimentation and filtration, leaving a clear solution. After precipitation of the hydroxide, Al_2O_3 powders can be obtained through heat treatment at their transition temperatures. Due to increase in Al_2O_3 particle on the surface of matrix, the plastic deformation of matrix can be resisted with the presence of Al_2O_3 which act as a barrier to the moment of dislocation which causes the more wear resistance than base alloy.

IV. TWIN-ROLL STRIP CASTING PROCESS

The twin-roll strip casting process is based on the concept originally proposed by an English engineer, Sir Bessemer. This process involves feeding of molten metal between two counter-rotating rolls, which act as the cooling and deformation elements, to solidify the molten metal into sheet. Twin-roll strip casters can consist of either equal sized rolls or unequal sized rolls. These rolls may be arranged horizontally, vertically or inclined. Presently, twin-roll casting of clad strips is carried out only under laboratory conditions and has not been realized commercially yet. This is due to the lack of process stability during the clad strip production and the low quality of the aluminum layer surface of the strips. Application properties of the clad compounds are defined by the bonding strength as well as by the microstructure and mechanical properties of its layers. The main drawback of twin-roll cast aluminum-steel clad strips is the presence of a partially cast microstructure in the aluminum layer. This is due to the inhomogeneous temperature distribution across the aluminum layer during rolling in the caster. The surface layer of the aluminum has a lower temperature and thus deforms less than the inner layers, so the cast structure formed during the solidification remains almost non-reworked. The ultimate goal in twin-roll strip caster is to cast thinner, wider, and faster with minimizing the macro- and micro defects on the strip surface. Casting wider and faster directly increases the productivity, while casting at a reduced gauge is an advantage in a way that it can save subsequent cold rolling steps.

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The main task of the processing of clad strips is improving the aluminum layer properties while retaining the bonding strength of the compound as well as the steel layer properties. This imposes certain limitations on the use of conventional methods of cast strips processing. It has been shown that heating of clad aluminum-steel strips to a temperature of 350°C to 400°C leads to an intensive growth of the intermetallic phase layer. It was recognized long back that proper design of tundish is important to maintain precise control of molten metal head in the tundish and to ensure a regular, uniform, turbulent-free melt to the roll bite at any casting speed. A typical metal feeding system to the roll gap for TRC of aluminum alloys is given in reference. Inclusions in the melt can be reduced by passing the molten metal through degassing and filtration units. In TRC of aluminum alloys, temperature of the melt is close to the melting point as it enters the roll and as low as 250°C as it leaves the roll gap. Due to significant differences in the yield stress values of aluminum and the steel at the temperatures of twin roll casting the plastic strain during rolling in the caster is localized in the aluminum layer. By usage of specified parameters of continuous forming plastic strain in the aluminum layer amounted to 30%. The range of alloy applicability of twin-roll caster is inherently limited because of the squeezing action of the solidifying mushy zone. The elemental segregation is severe, and therefore most of the industrial applications have been the low alloyed products. The thin strip quality in terms of two vital parameters, microstructure, and segregation is significantly affected by the solidification characteristic of the strip. The conversion from liquid to solid includes a semisolid region, that is, mushy zone. When the solidifying metal has reached adequate strength, the material experiences a degree of hot working before leaving the roll bite, which allows changes in the geometrical properties and microstructure of strip. This allows a better adhesion of the two shells to each other, avoiding voids and porosity in the center of the strip. So the twin-roll strip casting process combines solidification and deformation into a single process. The solidification phenomena in twin roll strip casting process depend on the process parameters of twin-roll strip caster: Diameter of the roll, Roll material, Casting speed, Roll gap, Metal delivery system and Metal-roll heat transfer coefficient.

Figure 1 Rolled strip

Hardness test

Following specifications of Rockwell hardness tester

- The indenter used- ball 1/16” diameter
- Major load applied 100 Kg
- Hardness scale- Rockwell ‘B’
- Pointer position on the dial at –B – 30 (inner scale)

Hardness Test at 6 rpm 675 ^{o}C

Sl no.	Left (mm)	Middle (mm)	Right (mm)
1	84	80	80
2	83	82	81
3	85	81	80
4	84	80	80
5	83	80	79

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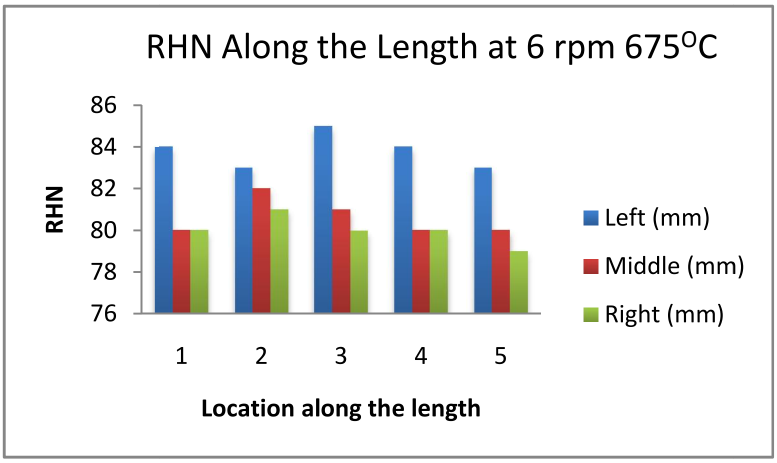

Speed 6 rpm Temp 680°C			
Sl no.	Left (mm)	Middle (mm)	Right (mm)
1	80	83	81
2	79	79	80
3	76	79	80
4	79	80	68
5	81	84	82

Table 5.12: Hardness Test of MMC at 7 rpm 675^{O} C

Sl No.	Left (mm)	Middle (mm)	Right (mm)
1	90	89	100
2	90	87	92
3	96	87	100
4	94	91	96
5	93	93	91

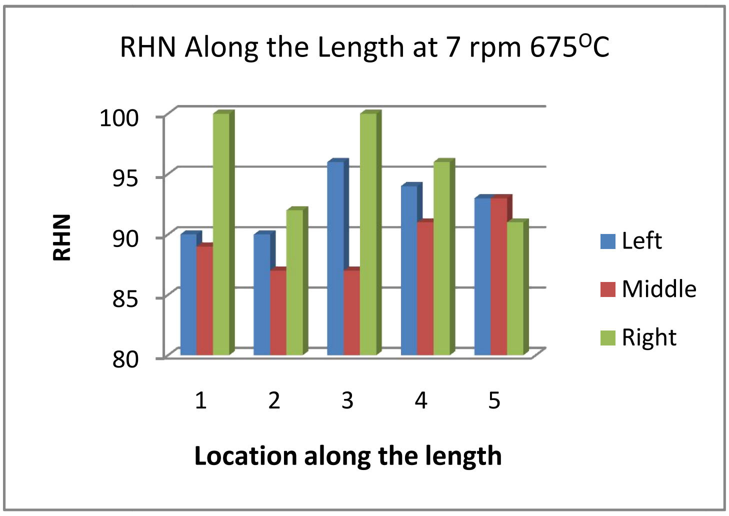

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Table 5.10: Hardness Test at 6 rpm 680 C

Sl no.	Left (mm)	Middle (mm)	Right (mm)
1	80	83	81
2	79	79	80
3	76	79	80
4	79	80	68
5	81	84	82

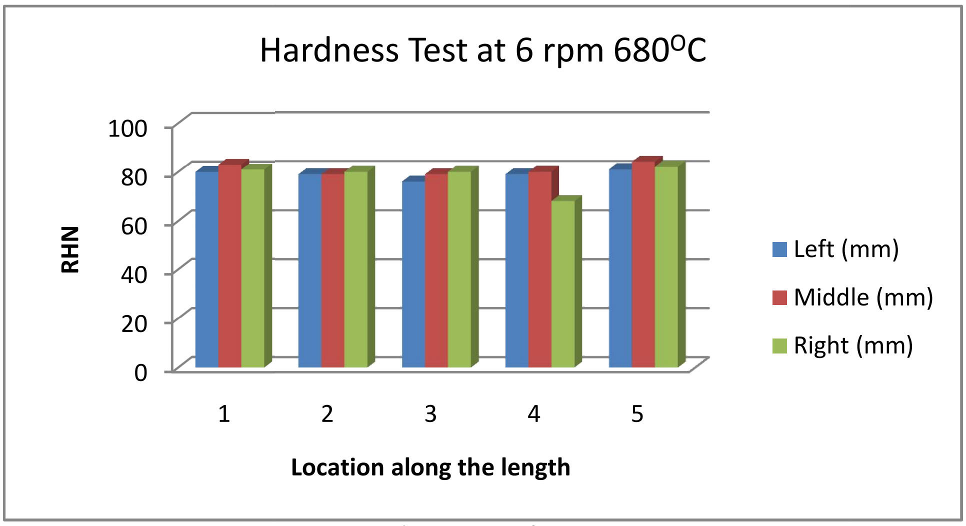
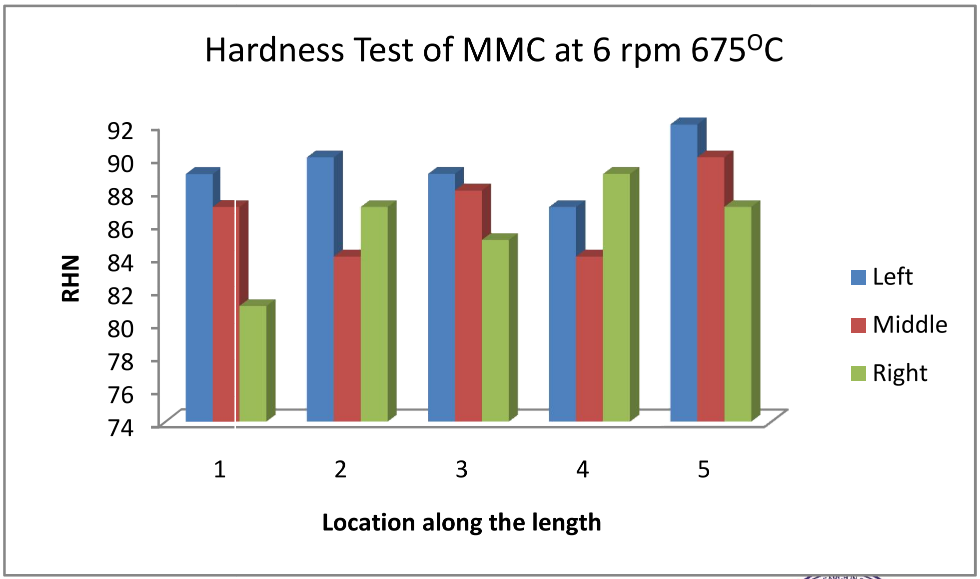


Table 5.13: Hardness Test of MMC at 6 rpm 675 C

Sl no.	Left	Middle	Right
1	89	87	81
2	90	84	87
3	89	88	85
4	87	84	89
5	92	90	87



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V. QUALITY OF THE TWIN-ROLL CAST STRIPS

The main benefit of TRSC process is based on the reduction of large number of processing steps and production costs. However, TRSC process produces thin strips where good surface quality is required, since only limited secondary processing is available to modify these parameters. Cracking during subsequent rolling and forming may be caused by internal and external defects. In twin-roll strip casting process, the quality of the strips is an important issue. Regarding the surface quality of the strips, the main defects in twin roll cast strips are longitudinal cracks, transverse cracks, and small depressions or wrinkles. The formation of longitudinal cracks in the strip surface produced by twin-roll strip casting process has been studied by several groups of researchers. Longitudinal cracks occur in the center part of the strip surface. It is caused due to uneven heat transfers across the strip width, uneven contraction strain generated due to uneven cooling, crack which is formed resulting from the build-up of heavy localized tensile strain. The uneven heat transfer occurred due to (i) free surface fluctuation, (ii) non uniform temperature inside the molten pool, and (iii) variation of heat transfer across the roll width. This tensile strain in the surface region with delayed solidification is responsible for the formation of crack. Transverse cracks occur randomly and especially in the initial stage of casting operation which is caused by the fluctuation of the free surface of the molten pool. This occurs when the two solidification fronts forming on the surface of the rolls meet before the roll nip. So an adequate combination of casting speed and roll separating force for certain strip thickness eliminates the cracks.

Internal defects.

The centerline segregation in the TRC strip is due to the segregation of solute elements which are pushed to the center from the two opposite advancing solid/liquid interfaces of the growing grains. Under the roll pressure, the solute-rich cold liquid squeezes out from the central region to the hot liquid region and pumps back the hot liquid to the mushy region where it melts the primary solid. When liquid flows from a cold to a hot region in a casting, the liquid must change its composition. Thus subsequent solidification results in the formation of solute-rich channel. The channel segregates form near the center of the strip and are promoted at higher roll speed. The deformation segregates form when solid and liquid are deformed together. ***Buckling.*** Buckling in thin twin-roll cast sheets has been reported by several researchers, where one side of the sheet is tight and the other is long. For the wide freezing range alloys, the long edge deformed heavily compared with the short edge. They related the buckling to the non-uniformity of the solidification process resulting in more forward slip over the part of the strip. The buckling was found to be alloy specific and could be reduced or eliminated by increasing the coiler tension. To ***minimize*** the defects in the as-cast strip, it is necessary to reduce the free surface fluctuation in the molten pool and uneven heat transfer, which in turn can be minimized by increasing the casting speed. So this is the clear evidence of the importance of the high speed vertical twin-roll strip caster in producing quality strips.

One of the major differences in TRC and normal casting processes is the difference in cooling rates and under cooling generated due to the variation in cooling rates. Thus, more constitutionally under cooling related growth is seen in normal casting and it is thermal in TRC.

VI. CONCLUDING REMARKS

Aluminum strips are obtained at different pouring temperatures and is compared with each other for its evenness of edges and continuity. Different roller speeds are set and strips are obtained to ensure that melt has sufficient time to have proper solidification. The rollers are preheated sufficiently to prevent the melt from adhering to it. Hardness is uniformly distributed along the length in both cases. In both cases the tensile strength is increased

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