ACTION OF WATER COOLED COPPER END CHILLS DURING SOLIDIFICATION ON FRACTURE BEHAVIOR OF ALUMINUM ALLOY/QUARTZ MMCs.

The present investigation aims at producing cast aluminum alloy-quartz particulate composites in moulds containing water cooled copper end chills by dispersing quartz particles in molten aluminum alloy above the liquidus temperature, the size of the particles dispersed being between 50 to 100μm. The dispersoid being added ranges from 3 to 9 wt.% in steps of 3 wt..%. Melting of the matrix material was carried out in a composite making furnace at 760 deg C in an inert atmosphere, quartz particles preheated to 700 deg C were introduced evenly into the molten metal alloy by means of special feeding attachments. Meanwhile, the molten composite was well agitated by means of a mechanical impeller rotating at 600 rpm to create a vortex. The resulting composites cast using water cooled copper end chills were tested for their fracture behavior. Water cooled copper end chills of different thickness (10 mm to 25 mm in steps of 5 mm) was used to study the effect of Volumetric Heat Capacity (VHC) of the chill on fracture toughness, strength and microstructure of the composite. The superior mechanical properties of the composite developed particularly their strength and fracture toughness are discussed in relation to their microstructure. Results of the investigation reveal that;

1. Microstructural studies indicate good bonding with consistency in the matrix.

2. As the quartz content is increased the strength and fracture toughness increase remarkably and is highly dependent on the location of the casting from where the test specimens are taken.

3. Volumetric Heat Capacity (VHC) of the water cooled end chill and chill material (copper) which takes into account the rate of chilling does significantly affect the strength and fracture toughness.

4. SEM analysis showed that, large particles and the regions of clusters of particles were found to be the locations prone to damage the composite prior to final fracture.

However, it was found that, the mechanical properties are not deteriorated as compared to those of the matrix alloy. It is also discovered that a small amount of quartz particles and chilling are sufficient to cause a fairly large change in microstructure and mechanical properties.

1. INTRODUCTION.

1.1 Freezing of Aluminum Alloys:

It is well known that Al composites freeze over a wide range of temperature are difficult to feed during solidification . The dispersed porosity caused by the pasty type of solidification of long freezing range alloy castings can be effectively reduced by the use of chills. Chills extract heat at a faster rate and promote directional solidification. Therefore chills are being widely used by foundrymen in the production of quality castings (Joel Hemanth[1]). There have been several investigations on the influence of chills on the solidification and soundness of long freezing range alloy castings (Joel Hemanth[2]). However, the analysis related to water cool chilling of Al-quartz composite is undertaken because it is apparent from the examination of the literature that this subject had not been dealt so for.

1.2 Microporosity in Aluminum Composites:

With the increase in the demand for quality composites, it has become essential to produce aluminum composites free from unsoundness (Jacob, S and Drouzy, M [3]). Al based composite castings, widely used in aerospace industries are prone to unsoundness in the form of microshrinkage (Kutumbarao, G.V, and Panchanathan, V,[4]). Microshrinkage or dispersed porosity in the composite can be minimized by judicious location of chills (Lin, W.H, and Jen, M.H.R, [5]). In spite of increased application of chills in Al alloy founding, there is no data available on the action of water cooled copper chills on the soundness of Al-quartz composites (Murthy, K.S.S, & . Prabhakar, K.V, and Seshadri, M.R, [6,7]). It has been shown that chilling has an effect on the structure and soundness of Al alloy castings (Redmske, J, & Radhakrishna, K, and Seshan, S. [8,9]).

2. EXPERIMENTAL PROCEDURE

2.1 Chemical Composition:

The present investigation aims at producing cast aluminum alloy-quartz particulate composites in moulds containing water cooled copper end chills by dispersing quartz particles in molten aluminum alloy above the liquidus temperature, the size of the particles dispersed being between 50 μm to 100μm. The dispersoid being added ranges from 3 to 9 wt% in steps of 3%. The resulting composites cast using water cooled copper chills were tested for their mechanical properties.

Chemical composition of the commercial grade aluminum alloy used as the matrix is given in table 1. Chemical composition and properties of quartz particles are as follows: Density: 2.8 gm/cc, Hardness :330 BHN, Chemical composition: SiO_2, Melting point: 1800^0 C

Table-1: Chemical composition of the matrix alloy.

Elements	Zn	Mg	Fe	Al
%wt composition	3.01	3.00	0.001	93.99

2.2 Chilled composite preparation procedure:

The alloy is introduced into a specially designed bottom pouring composite melting furnace. After melting the charge at around 760°C (heated in an inert atmosphere for 45 minutes at 700°C), preheated quartz particles at 700°C are introduced evenly into the molten metal by means of special feeding attachments. During this process, the molten metal is well agitated by a mechanical impeller specially to create vortex motion. The speed of the impeller is maintained at 600 rpm. The process of dispersing the particles is completed with in one minute. After the complete injection of the dispersoids, the molten metal is again stirred for few seconds. Later, at 740°C, it is poured into a mould containing water cooled copper end chills. The moulds for the plate type of castings 225*150*25 mm (AFS standard) were prepared using silica sand with 5% bentonite as binder and 5% moisture and finally they were dried in an air furnace. Ingots were cast employing different thickness of water cooled copper chills in order to study the effect of heat capacity of the chill on the strength, fracture and microstructure of the composite developed. Length and breadth of the chill were kept constant at 170 and 35 mm respectively.

2.3 Testing Procedure:

Fracture toughness tests were performed using a closed-loop INSTRON servo-hydraulic material testing system in accordance with ASTM E 399-1990 standards. The method of testing involved the 3-point bend testing of notched specimens which had been pre-cracked by fatigue. Fully reversed push-pull, total strain-controlled, tension-compression (R= -1) fatigue tests were performed. The tests were performed in a controlled laboratory air environment (temperature 26 deg C, relative humidity 56%). From the load, the stress intensity factor K_{IC} (which is a measure of the fracture toughness of the material) was calculated using equations which have been established on the basis of elastic strain analysis. The validity of this method depends on the establishment of a steep crack condition at the tip of the crack in a specimen of adequate size. All these conditions were fulfilled in this experiment.

Tension tests were performed using Instron tension testing machine on AFS standard tensometer specimens. Each test result was obtained from an average of at least three samples of the same location. The tensometer specimens for the strength tests were prepared according to American Foundrymen Society (AFS) standards. The specimens for strength and fracture toughness were taken from various locations in the casting namely chill end, 75, 150, 225 mm from chill end, the latter being situated at the riser end. The longitudional axes of these specimens were parallel to the longitudinal axis of the chill set during casting.

Microscopic examination was conducted on all the specimens using VG 9000 scanner as well as Neophot-21 metallurgical microscope. Various etchants were tried but dilute Kellers etchant proved to be the best and was therefore used. Photomicrographs of all the specimens were taken to study their micro-constituents and the distribution of quartz particulates. SEM photographs were also taken of all the fractured surfaces after the testing to study the fracture mechanism.

3. RESULTS, DISCUSSIONS AND CONCLUSION.

3.1 Microstructure.

The microstructural examination and fractographical analysis revealed good distribution of quartz particles throughout the matrix. The microstructure of the chilled Al/quartz composites containing 6 wt% and 9 wt% quartz cast using copper chill of thickness 25 mm are shown in Figs. 1 and 2 respectively.

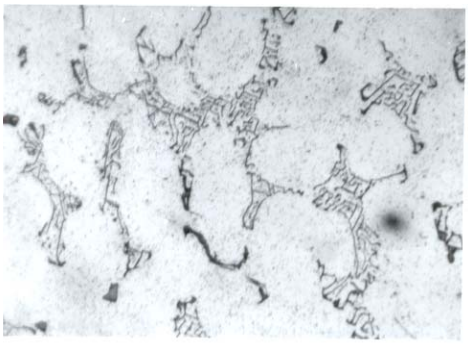

Fig. 1 Microstructure of 6 wt.% quartz chilled MMC (Magnification 500 X)

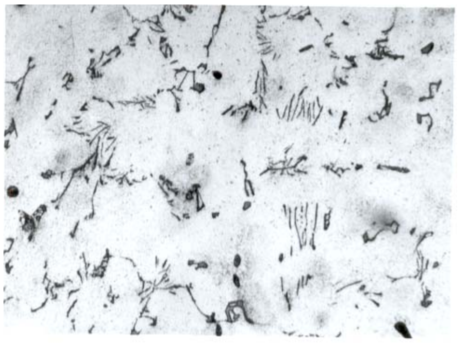

Fig. 2 Microstructure of 9 wt.% quartz chilled MMC.(Magnification 500 X)

These photomicrgraphs show that the quartz particles are of nearly uniform size and are uniformly dispersed in the aluminum matrix. However, Mg was seen to have migrated to the grain boundaries and the particle-matrix interfaces. This migration of alloying elements into the grain boundaries leaving behind the dispersoids in the grains results in a higher concentration of quartz within the grains, which may be one of the main reasons for the increase in fracture toughness and strength of the composite developed, as will be described below.

3.2 Ultimate Tensile Strength (UTS).

Table 2 tabulates the UTS of specimens taken from the chill end of the casting for composites cast using different types of chills. It is evident from this Table that for a particular chill, the UTS of the composite increases as quartz content is increased up to 6 % by weight, beyond which it drops again. There is therefore no advantage in reinforcing the Al matrix with quartz contents above 6 wt % as far as UTS is concerned. For a particular chill, UTS can be seen to decrease with distance from the chill up to a distance of about 150 mm, beyond which it increases again. In Table 2 , it can be seen that if the location of a specimen is kept constant, of the four types of chills used, the copper chill with 25 mm thickness is the one which produces specimens of the highest UTS, followed by 20, 15 and 10 mm thick chillss in that order. This shows that as heat conductivity of the chill increases as the chill thickness increases, so does the UTS of the specimen. In other words, if all other factors are kept constant, the faster the heat extraction from the molten MMC during casting, the higher would be the UTS of the cast MMC.

Table 2. UTS of Al/quartz composites with various quartz contents cast using water cooled chills of different thickness.

Thickness of water cooled Cu chill	UTS, MPa (at the chill end)		
	3 wt% quartz	6 wt% quartz	9 wt% quartz
25	116	144	132
20	114	138	128
15	102	135	119
10	97	121	115

3.3 Fracture toughness

The manner in which stress response varies with the number of cycles and the plastic-strain amplitude is an important feature of the low-cycle fatigue process. The cyclic stress required for pre-cracking the specimen provides useful information pertaining to the mechanical stability of the intrinsic microstructural features during reverse plastic straining. This and the ability of the material to distribute the plastic strain over the entire bulk of the material are the two key factors governing the cyclic response of a material (Starke, E.A, and . Lutjering, G, [10]).

The experimental results of the fracture toughness tests done on specimens taken from the chill end for composites cast using different types of chills are shown in Table 3.

Table 3 Fracture Toughness of Al alloy/Quartz chilled composites.

Fracture Toughness, MPa ♦m			
Thickness of water cooled Cu chill block, mm	3 wt% dispersoid	6 wt% dispersoid	9 wt% dispersoid
25	14	19	17
20	10	17	16
15	9	11	10
10	6	7	7

From these results, it can be seen that changing the thickness of chill does have a pronounced effect on the fracture toughness of the material. In fact, increasing the rate of chilling by increasing the Volumetric Heat Capacity (VHC = volume * density * specific heat) of the chill tends to result in an increase in the fracture toughness of the material. It can be seen that if all other factors are kept constant, water cooled copper chilled castings cast using 25 mm thick chill invariably have the highest fracture toughness followed by castings cast using chills of other thickness. This agrees with the deductions made by the author in an earlier paper (Joel Hemanth[11]) that increasing the rate of chilling tends to result in an increase in the fracture toughness of the material. Another factor affecting the fracture toughness of a specimen is its quartz content. The fracture toughness is seen to increase as quartz content is increased up to about 6 percent by weight, beyond which the fracture toughness drops again. There is therefore no advantage in adding more than 6 wt % of quartz to the matrix material since it would cause the MMC to become more brittle.

Figs. 3 and 4 show the SEM photographs of fracture surfaces of typical specimens cast using copper chills of 25 mm thick. Of all the various types of chills used in this research, copper chill of 25 mm thick provide the highest rate of heat extraction during casting. The photographs reveal a ductile mode of fracture, accompanied by isolated micro-cracks in the matrix as shown in the figures. Large areas of the fracture surface were covered with a bimodal distribution of dimples, indicative of ductile rupture. A dimple is a half void and the voids were formed mainly at the particle-matrix interface. However, growth of the voids was limited by the competing and synergistic influences of the brittleness of the reinforcing quartz particles and the cyclic ductility of the matrix material. In contrast, specimens cast without chills displayed low ductility with fracture essentially normal to the stress axis (Joel Hemanth [12]).

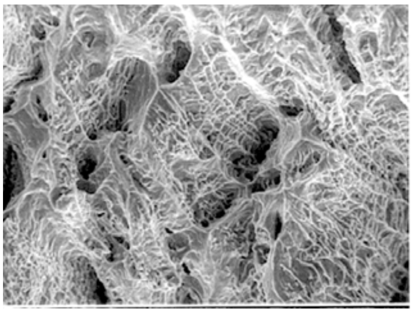

Fig. 3 Fractograph of 6 wt.% quartz chilled MMC (Magnification 100 ∝m)

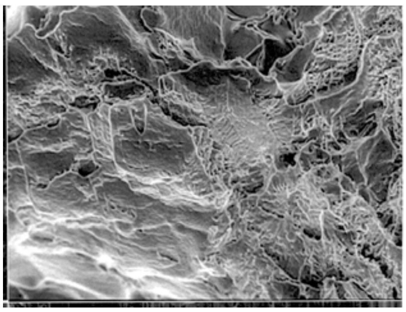

Fig.4 Fractograph of 9 wt.% quartz chilled MMC (Magnification 100 ∝m)

The mechanisms which control the variation of fracture toughness of chilled Al-quartz composites are dependent on both microstructure and strain range. The possible micro-mechanisms controlling the fracture behavior during cyclic loading are ascribed to the following synergistic influences:

a) Load transfer between the soft Al matrix and the hard brittle quartz particulate reinforcement.
b) A pre-existing high dislocation density in the Al matrix caused by the presence of the hard, brittle quartz particulates.
c) Hardening arising from constrained plastic flow and tri-axiability in the Al matrix due to the presence of the brittle quartz reinforcements. As a direct result of the particles resisting the plastic flow of the matrix, especially in chilled composites, an internal stress or back stress is created.
d) Dislocations arising from competing influences of back stresses in the plastically deforming composite matrix and due to plastic relaxation by the formation of dislocation loops around the hard quartz particulates.
e) Residual stresses generated in the Al matrix and dislocations arising from the mismatch in thermal expansion coefficients between the soft matrix and the hard reinforcement quartz particulates.

During cyclic deformation it seems possible that the mismatch that exists between the brittle reinforcing particle and the ductile matrix favors concentration of stress at and near the particle-matrix interface, causing the matrix in the immediate vicinity to fail permanently or the particle to separate from the matrix. In addition, the improvement in fracture toughness when water cooled chills are employed during casting can also be attributed to the refining of the grain structure of the matrix.

It is thus concluded from the above research that, for the Al/quartz composites tested, both UTS and fracture toughness of the chilled composites were found to increase as the content of quartz particulates was increased up to about 6 percent by weight. Further addition of quartz particulates only serves to reduce these two mechanical properties. There is therefore no advantage in increasing indefinitely the quartz content in such MMCs. If all other factors are kept constant, the faster the heat extraction from the molten MMC during casting, the higher would be the UTS and fracture toughness of the castings. Fracture analysis of the MMCs cast using water cooled copper chills showed ductile rupture with isolated micro-cracks and a bimodal distribution of dimples on the fracture surface. In contrast, fracture analysis of the MMCs cast without chills revealed brittle failure with separation of the quartz particles from the matrix.

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