A Review on Actions of Chills on Microstructure, Mechanical, Corrosion and Tribological Behaviour of Nickel and Aluminium Based Metal Matrix Composites

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Abstract: Metal matrix composites (MMC) are known to possess good combination of properties including high specific strength, specific modulus, good wear resistance, corrosion resistance and damping capacity. To meet the ever-increasing demand of modern-day technology, metallurgical aspect of MMC is being constantly explored for the improvement of metallurgical properties. Applications of chills in the processing of MMC are found to have an affect on the metallurgical properties with promising results. This paper reviews nickel and aluminium based MMCs processed through the action of various chills. The paper details the influence of chills on microstructure, mechanical, corrosion and tribological properties. Chills made from both metallic and non-metallic viz., copper, mild steel, cast iron, graphite, aluminium and silicon carbide are discussed. Compared to other chill materials, copper chills are found to produce MMC with better metallurgical properties.

Keywords: Nickel alloy, Aluminium alloy, Chills, Stir casting.

1. Introduction

Metal matrix composites (MMC) are in general, class of new materials tailored to suit a particular application. Nickel based MMC materials are gaining importance in critical functional parts such as turbine blades of space-crafts, aerospace, marine or power plants owing to extraordinary combination of properties like high temperature mechanical strength, toughness combined with superior corrosion and oxidation resistance. Aluminum based MMC materials have been considered in applications of the automotive and aircraft industries for its high specific strength, low density, high wear resistance combined with high-quality surface finish, styling details, and processing options. Novel processing techniques are being attempted constantly to improve the performance of the MMC. Both liquid state [1] and solid state [2] routes are used to develop MMC. Literatures indicated that liquid state routes are found to produce better results with homogeneous property.

In liquid route, fluidity of the molten metal plays important rule in filling the mould cavity. Fluidity gives “empirical measure of the distance a liquid metal can flow in a specific channel before being stopped by solidification [3]”. Lack of fluidity of molten metal leads to partial filling of cavity. Thin or complex sections of mould needs special attention in case of molten metal are found to have lesser fluidity. Chills known to “extract heat at a faster rate and promote directional solidification [4]” are found to be useful in nickel and aluminium based MMC castings which are associated with pasty mode of solidification. Literature indicated application of chills both external and internal made of both metals and non-metals viz. copper, mild steel, cast iron, aluminium, graphite and silicon carbide. In this paper an attempt is made review the literature on action of different chills and its effect on microstructure, mechanical, corrosion and tribological behaviour of nickel and aluminium based MMC.

2. Processing of MMC using stir casting

MMC is conventionally fabricated using liquid state processing. Stir casting technique is more popular in liquid route for producing MMC in large quantity. Stir casting has advantage over other processing techniques owing to its ease of production of large sized components. Further, stir casting is most economical among all other available processing techniques. Figure 1 gives detailed steps followed in stir casting of MMC.

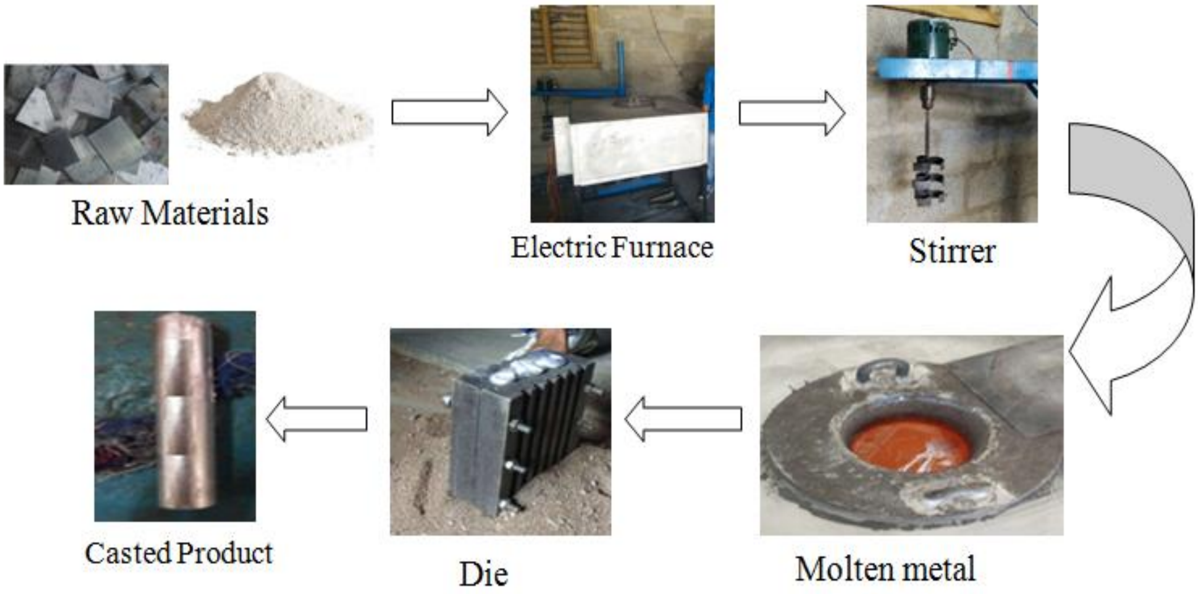


Figure 1: Stir casting of MMC

Matrix materials are melted in an electric furnace and reinforcement particulates were preheated for removing moisture content. Further, preheating reduces mismatch of thermal expansion coefficient between the matrix and reinforcement of composites. With the help of feeding attachment, reinforcements of required composition are introduced into molten metal alloy bath. A stirrer is used for mechanical mixing and even distribution of reinforcement. In general mixing speed is set at 760rpm for about 15 minutes. Sand moulds are prepared by using silica sand with 5% bentonite as binder and 5% moisture according to American Foundry men Society and are dried in an air furnace [5]. Chills are attached at the required position of the sand mould. Finally, the melt is poured into the moulds to produce final cast product.

3. Action of Chills on microstructure, mechanical, tribological and corrosion properties

3.1 Nickel based MMC

G Purushotham and Joel Hemanth [6-7] investigated action of chills on nickel alloy /silicon dioxide MMC processed by stir casted for its corrosion behaviour. The chills of different materials like copper, mild steel and silicon carbide of 25mm thickness are considered for the study.
Microstructural of the chilled MMC is reported have finer grain size when compared to un-chilled cast nickel alloy. Particulates in the matrix are reported to be distributed uniformly with no agglomeration. Strong interfacial bonding is reported to be established between particulate and matrix. Chill along with chilling rates are reported to have influence on the fusion of the silica particulate with matrix, directly influencing the corrosion behaviour of nickel MMC. It is reported found that the corrosion resistance increased with an increase in the dispersoid content up to 9wt%. Further it is reported that corrosion resistance is improved in copper chills when compared to silicon carbide chills (Figure 2).

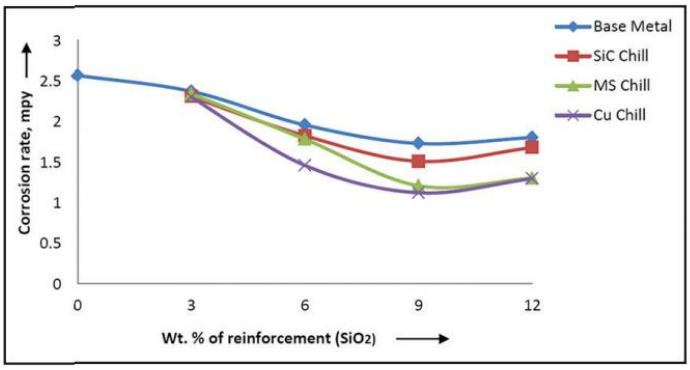


Figure 2: Corrosion rate v/s Wt. % of reinforcement under the influence of different chills [6]

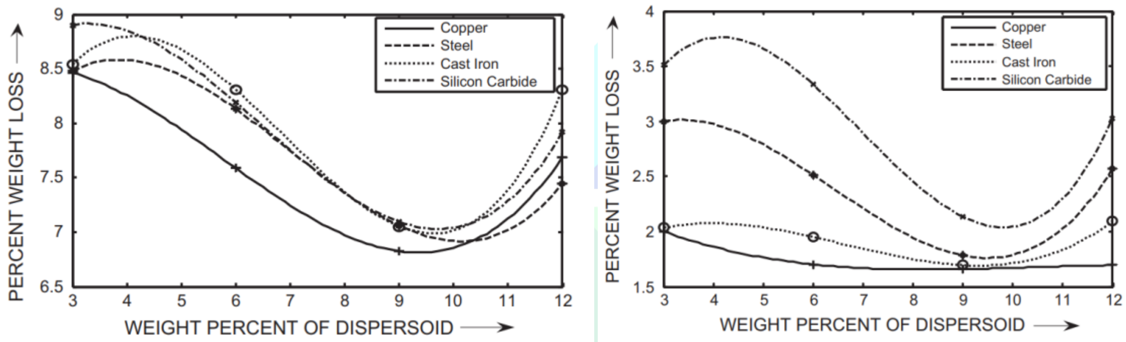
Anil Kumar et al. [8] reported the action of cryogenically cooled copper chills in developing a Ni- alloy based MMC with garnet particles as reinforcement. The method used to fabricate the MMC is by stir casting associated with liquid route process. Copper chills in block shapes of varying thickness were brazed to hollow mild steel blocks. Liquid nitrogen is reported to be circulated to create cryogenic effect.
Microstructure of the chilled MMC is found to have refined grains with dispersoid distributed uniformly and better bonding with matrix. Casting porosities are found to be minimum. Mechanical properties of chilled MMC is reported to yield improved results with tensile strength and hardness increased by 13% and 14% respectively when compared to MMC developed without chills. Optimum thickness of the chill is found to be 25mm, indicating that of heat capacity of cryogenic chill is highly dependent on the chilling rate and chill thickness.

G Purushotham et.al [9] investigated the effects of chills on microstructure and mechanical properties of nickel alloy MMC. Composites consisting of nickel alloy as matrix and fused silicon dioxide (SiO_2) particles as the reinforcement in the matrix is prepared by stir casting technique. The chill blocks are made up of mild steel and silicon carbide materials of constant thickness 25mm. Chill blocks are placed adjacent to one end of the mould.
Microstructure studies indicated that dispersoid is spread homogeneously due to the stirring action. Micro porosities normally found in casting process are reported to be absent in the microstructure. Bonding is found to be perfect between matrix and dispersoid, due to preheating of the dispersoid. Mechanical properties of chilled MMC are reported have increased strength and hardness for reinforcement upto 9 wt% as against the results obtained for non-chilled casting.

3.2 Aluminium based MMC

Pavithra H S et.al [5] studied the influence of chills on microstructure and mechanical properties of aluminium hybrid metal matrix composite. Aluminium alloy with reinforcement's viz. Quartz and Carbon are used to produce hybrid MMC. Chills materials included copper, silicon carbide, steel and iron. Chills are attached to sand moulds at one end. Copper chilling is reported with microstructure of fine grains. Reinforcements are reported to be distributed uniformly across the grains with good bonding visible between the components of composites. Grain sizes are reported to be increased with chills made of steel and iron. Larger grain size was obtained for silicon carbide indicating poor chilling action. Mechanical properties are reported to be optimum for 3 wt% carbon and 9wt% quartz in the hybrid MMC.

Joel Hemanth [10] reported the wear behaviour of chilled aluminium alloy metal matrix composites. Aluminium alloy is with fused silica particles. Sand mould is used casting with different chills like Copper, Steel, Cast iron. Further action Silicon Carbide a non metallic chill is also used for the study.
Microstructural studies showed that there is uniform distribution of the dispersoid as well as good bonding between matrix and the dispersoid. Microstructures of the copper chilled composites are finer than that of other metal matrix composites. Strong interfacial bond is also observed with no agglomeration between the matrix and dispersoid. The reported results revealed that the wear resistance of the aluminium alloy MMC increased as the dispersoid content increased (up to 9 wt.%).Further "volumetric loss of the material is inversely proportional to the hardness value of the material [10]". Chilling action is reported to increase the hardness, in turn increasing the wear resistance. Percentage of weight loss is less in wet wear condition compared to the dry condition (Figure 3). Copper and steel chills are found to be better compared to cast iron and silicate carbide chills.



(a) **(b)**

Figure 3: Weight loss v/s Dispersoid for composites using various chills tested under (a) Abrasive (Dry) wear condition (b) Slurry (Wet) wear condition [10]

Nityanand Bandekar et.al [11] investigated the tribological (three body abrasion) behaviour of hybrid composite of aluminum alloy. Composites consist of aluminum alloy LM-13 as matrix with garnet and carbon as reinforcements. Conventional stir casting technique is used to fabricate the composites with chill cast technique. Various chill materials like copper, steel, iron and silicon carbide are used in casting process.
Microstructural characterization of the composite revealed a uniform distribution of reinforcements with minimum clustering. Addition of garnet and carbon reinforcement decreased the wear rate of hybrid composites. Directional chilling effect improved the wear resistance of the composites. Copper chills are found to be more effectively compared to other chill materials viz. steel, iron and silicon carbide (Figure 4).

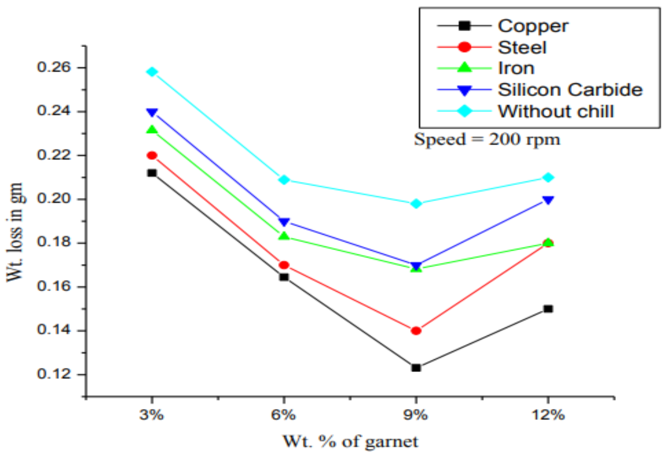


Figure 4: Weight loss v/s Wt. % of reinforcement for abrasion test [11]

Syed Ahamedet.al [12] reported wear behaviour of chilled aluminium alloy MMC. Composites are prepared by stir casting method with aluminium alloy LM-13 as matrix, Kaolinite and carbon as reinforcements. MMCs are cast using cryogenically cooled copper chills of varying thicknesses such as 10mm, 15mm, 20mm and 25mm placed in a mould at one end. Dry slide wear tests are carried out using a pin-on-disc wear testing machine.
Micro structural analysis reported finely refined matrix structure using cryogenically cooled copper chills. Wear resistance is found to increase with increase in dispersoid content up to 9 wt%. Chill of thickness 25mm reported higher wear resistance indicating importance of chill thickness in chilling action.

4. Conclusion

Actions of chills are reported to influence the metallurgical properties of both Nickel based and Aluminium based MMC. Chills are made from both metal and non-metals. Some of the chills are used in cryogenic condition. Following conclusions were drawn from the available literatures in the open source.

- Microstructure of the chilled composites is finer than that of unchilled matrix alloy, Porosities associated with casting are reported to be minimum and Particulate reinforcement is distributed uniformly across the metal matrix.
- Volumetric heat capacity of the chill and the cryogenic effect are found to increase the amount of heat absorbed. Cryogenic chills reported finer grain structure with good bonding established between particulate reinforcement and matrix material compared to non-cryogenic chills.
- Hardness and mechanical strength of the composite are found to depend on the wt. % of the dispersoid and thickness of chilling.
- Chill material and the dispersoid content significantly affect the corrosion and tribological properties of the composites.
- Copper chills are found to be more effective producing better results in terms of finer grain size. Reinforcement distributions are uniform across matrix material. Bonding is reported to be strong between interface of reinforcement and matrix. Chilling actions are found to less effective for materials like steel and cast iron, with microstructure indicating larger grain size and lesser mechanical strength. Poor metallurgical results are obtained for silicon carbide chills and MMCs produced without any chills.

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