Effect of Almandine on Microstructure and Corrosion properties of Nickel super alloy (K500) Composite for Aerospace Gas Turbine Application

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Abstract: Corrosion is one of the major threats that the engineering materials are prone to and aerospace gas turbine materials are not an exception. The increased rate of corrosion results in the erosion and deterioration of material and its properties. The rate of increase in corrosion at higher temperature is found to be exponential in gas turbines. The review of experimental works carried out indicates that the metal matrix composite poses enhanced properties than the parental metal alloy. In order to curtail the rate of increase in corrosion, this experiment deals with the addition of Almandine (Garnet) to Nickel K500 alloy, with the help of chills for obtaining improved directional solidification in casting. The Almandine, the reinforcing material, added to the matrix material varies from 3% to 9% by weight, in steps of 3% of weight. The Process of melting is carried out in an induction furnace, and the molten composite is poured to the mould containing the chills. The resulting directionally solidified specimens are machined and tested for their microstructure and corrosion properties.

1. Introduction
The innovation and invention in engineering world is closely related to the development in manufacturing materials. We live in the world of dynamic change, and the materials are not an exception to it. The material applications and the engineering designs are constantly changing and it continues to accelerate. Higher efficiency and enhanced properties of materials result in the development of high efficient machine and better mechanism. Composite materials ever since inception led to revolutionary changes in aerospace materials. These materials play vital role in enhanced strength to weight ratio, improved corrosion resistance, higher wear resistance and hardness of the material, which is the need of the hour for materials in aerospace and marine application [1-3].

Range of research resulted in proving the versatility of nickel alloy, which includes the potential for superior hardness, higher resistance to abrasion, excellent resistance to high temperature oxidation, enhanced resistance to corrosion and micro creep. These materials also have the advantage of fabrication of discontinuously reinforced composite by the conventional metallurgical method. Nickel has the Face Centred Cubic structure, which makes it very formable. The entire spectrum of Nickel based super alloys are being developed mainly for the application in aerospace sectors [4-7].

With the growth in the production of superior quality of composites, it is mandatory to produce the nickel matrix composite, having null or minimum hardening imperfection. The hardening imperfection caused due to the scattered porosities and random shrinkage etc, are overcome majorly by directional solidification process [8-10]. The directional solidification is obtained by the use of suitable chills, which directs and fastens the rate of cooling, thus facilitating the unidirectional cooling, which in turn results in reduced material imperfections. The size, shape and thermo physical properties of chills play a vital role in extracting heat from the molten metal during the solidification. The efficiency
of the chills depends upon its capacity to absorb the heat from the molten metal. The parameters which define the efficiency of chill are volumetric heat capacity, specific heat and density of chill. The usage of chills certainly reduces the imperfections and improves the quality of the cast  [11-12]

2. EXPERIMENTAL DETAILS

2.1 Material Selection

The chosen matrix material for the experiment is Nickel K500 (Monel metal) alloy. Table 1 and 2 shows the chemical composition, physical and chemical properties of the matrix material respectively. The Almandine (Garnet) is selected as the reinforcement material and the table 3 and 4 shows the chemical composition, physical and chemical properties of reinforcement material respectively.

Table 1: Chemical Composition of Monel K500 alloy

| Element | Ni  | Cu  | C  | Si  | Mn  | P  | S  | Cr  |
|---------|-----|-----|----|-----|-----|----|----|-----|
| % by wt | 65.074 | 28.393 | 0.043 | 0.388 | 0.942 | 0.015 | 0.002 | 0.021 |

| Element | Mo | Fe | Ti | Co | Al | Nb | V |
|---------|----|----|----|----|----|----|---|
| % by wt | 0.013 | 1.523 | 0.799 | 0.034 | 2.741 | 0.01 | 0.001 |

Table 2: physical and mechanical properties of Monel K500 alloy

| Matrix Material | Density (g/cm³) | Melting Point (°C) | Coefficient of Expansion (µm/m.°C) | Thermal Conductivity (W/m.°C) |
|-----------------|-----------------|--------------------|-------------------------------------|-----------------------------|
| Monel K500      | 8.44            | 1315-1350          | 13.7                                | 17.5                        |

| Matrix Material | Tensile Strength (MPa) | Young’s Modulus (GPa) | Yield Strength (MPa) | Hardness (Rₚ₉₀) |
|-----------------|------------------------|-----------------------|---------------------|-----------------|
| Monel K500      | 1100                   | 180                   | 790                 | 28-40           |
Table 3: Chemical composition of Almandine (Garnet)

| Element   | SiO₂ | Al₂O₃ | Fe₂O₃ | MnO   | CaO     | TiO₂   | MgO     |
|-----------|------|-------|-------|-------|---------|--------|---------|
| % by wt   | 35-38| 18-20 | 28.5-31.5 | 0.75-1.25 | 1.5-2.0 | 0.75-1.25 | 5.0-6.0 |

Table 4: Physical and Mechanical properties of Almandine (Garnet)

| Reinforcement Material | Specific Gravity g/cm³ | Melting Point in ºC | Mohr’s Hardness | Refractory Index |
|------------------------|------------------------|---------------------|-----------------|-----------------|
| Garnet                 | 4.3                    | 1140-1280           | 7-9             | 1.83            |

3. Preparation of composites.

The entire process of casting is carried out in the foundry section. Monel K500 alloy is melted in the induction furnace. The addition of reinforcement material is carried out using the mechanical stirrer for the homogenous mixture. Initially the Nickel K500, matrix material is superheated to its melting temperature of about 1560 ºC and the Almandine, the reinforcing material is preheated to 600 ºC. These are blended appropriately and poured to the mould of size 225*50*25mm. Nitrogen gas is passed to the mould to remove the internal gas, since it is heavy, settles down in the cavity and pushes other gases out of the mould. The presences of chills in the cavity further facilitate the unidirectional cooling of the molten metal.
4. Composite Testing

4.1 Microstructure test

The test is conducted using NIKON – Japan, ECLIPSE LV 150 optical metallurgical microscope. Microstructure of the material is the enlarged view of the prepared surface of the material, which is magnified by the microscope. The different percentages of almandine reinforced nickel composite specimens are prepared as per ASTM standards for testing.

4.2 Corrosion Test

Corrosion is a slow and steady electrochemical attack process on the metals or alloys. The factors affecting the corrosion rate are mainly temperature, concentration of the reactants and the products. The rate of corrosion on the different percent of almandine reinforced nickel is determined by the Ferric Sulfate-Sulfuric Acid Test. The specimen with dimension 7*13*25mm is used for testing which weighs around 21 grams. The difference in the weight of the specimen after and before the corrosion is calculated and hence the corrosion rate is determined. This test method aims to detect the susceptibility to intergranular corrosion as influenced by variations in processing or composition, or both.
5. Results and discussions

5.1 Microstructure studies

Discussion: The microstructures study results of fabricated as deposited samples, were observed to be in concurrence with those predicted microstructures. It is witnessed from the microstructure revisions that the configuration was observed to be jam packed dendritic with only major dendrite arms noticeable and with no substantiation of precipitation or grain boundary isolation of solute atoms. Moreover, the dispersoid is seen extending equivalently and this is largely because of stirring and density differences. Closeness is unblemished between matrix and dispersoid owing to rewarming of the dispersoid. Micro porosities have also not been detected in the microstructure. The microstructure conceals the fine grain structure due to the influence of chilling.
5.2 Corrosion Test

Figure 5: plot of corrosion rate v/s weight % of Almandine (Garnet) for the composites cast with/without the influence of chill.

Discussion: The corrosion rate of the unreinforced matrix alloy (base metal) (corrosion rate=104 mpy) is higher than that of the metal matrix composites, because in the former the matrix alloy does not have much corrosion resistance to the acid media due to the absence of reinforcement. The addition of almandine (garnet) further reduces the corrosion rate since almandine is a hard ceramic that stays latent and is itself unpretentious by the acidic media during the tests. The outcomes display a change in the corrosion resistance as the garnet substance is augmented in the composite, showing that the intertwined garnet particulates impact the consumption attributes of the composites but not electrochemically. It is likewise seen from the plot that the corrosion rate is reduced as the dispersoid is built even up to 6% of reinforcement for composites cast utilizing distinctive chill.

6. Conclusion
a) Nickel based metal matrix composite can be casted successfully from electric induction furnace using stir casting method.
b) Microstructure of the chilled composites is superior (finer) than that of un-chilled matrix alloy with homogeneous distribution of almandine (garnet) particles. Strong interfacial bond was observed with no agglomeration between the matrix and the dispersoid.
c) Chill material and the dispersoid content however do significantly affect the corrosion properties of the composites. It was seen that the corrosion resistance increase with an increase in the dispersoid content up to 6 weight %. Hence this property of enhanced corrosion resistance and finer microstructure is most suitable for aerospace gas turbine material.

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