Available online at
www.ijacskros.com

Indian
Journal of Advances in
Chemical Science

Indian Journal of Advances in Chemical Science **4(3)** (2016) 235-240

Study of Physico-chemical Properties of Monel M-35-1 Nickel Alloy-fused Silica Metal Matrix Composite for Marine Application

G. Purushotham[1], Joel Hemanth[2]

[1]Department of Aeronautical Engineering, Mangalore Institute of Technology & Engineering, Moodbidri, Karnataka, India. [2]Department of Mechanical Engineering, HMS Institute of Technology, Tumkur, Karnataka, India.

Received 04th March 2016; Revised 07th April 2016; Accepted 14th May 2016

ABSTRACT

In the arena of engineering, metallurgists look for techniques to improve the mechanical and chemical properties of the materials. A review of a host of relevant literature on the composites leads to some important observations on the gap that prevails for developing the composite with increased strength to weight ratio, improved mechanical properties, and reduced corrosion rate with the addition of fused SiO_2 dispersoid for the nickel-based alloy. In this connection, an investigation has been carried out to fabricate and evaluate the strength, chemical properties, and corrosion resistance of chilled composites consisting of nickel matrix with fused silica particles (size 40-150 µm) in the matrix. The main objective of the present research is to obtain fine grain Ni/SiO_2 chilled sound composite having very good properties. The dispersoid added ranged from 3 to 12 wt. % in steps of 3%. The subsequent composites cast in molds containing metallic and non-metallic chill blocks (MS, SiC, and Cu) were tested for their microstructure, chemical properties, and corrosion behavior.

Key words: *Chills, Corrosion, Fused silica, Metal matrix composite, Nickel alloy, Scanning electron microscope, Energy dispersive X-ray.*

1. INTRODUCTION

The demand for functional materials to provide high performance posed challenges to the researchers, and continuous attempts are being made particularly in the areas of the design and development of novel processing techniques about alloys.

Nickel alloy-based metal matrix composites are the class of advanced materials that are well suited for pumps, valves, and automotive industries because of their strength, corrosion resistance, and for electric and electronic industry because of their high thermal and electrical conductivities [1,2]. In particular, the particle-reinforced metal matrix composites (MMCs) are attractive since they exhibit near-isotropic properties in comparison with the continuously-reinforced matrices. Many researchers reported the advantages of nickel alloy compared to other materials including the potential for high hardness, good abrasion resistance, improved corrosion resistance, and micro creep performance. Furthermore, fabrication of the discontinuously-reinforced nickel composite can be achieved by standard metallurgical methods [3-5].

With the increment in the interest for quality composites, it has become crucial to create nickel combination composites that are free from hardening imperfections. It is understood that Ni alloys solidify over an extensive variety of temperature and are hard to nourish amid cementing. Nickel composite is inclined to surrender as a small scale shrinkage. The scattered porosity brought about by the pale method of hardening can be successfully diminished through the utilization of chills. Chills concentrate heat up at a speedier level and advance the directional solidification. In this manner, chills remain broadly utilized by foundry engineers for the generation of comprehensive and excellence castings. Smaller scale contraction or scattered penetrability in the composite can be reduced by the reasonable area of chills [6-8]. Chills extract heat at a faster rate and promote directional solidification. Therefore, chills are widely used by foundry engineers for the production of sound and quality castings. Micro-shrinkage or dispersed porosity in the composite can be minimized by the judicious location of chills. Chills help to achieve a steep temperature gradient in the desired direction and at the desired location. As a consequence of using

*Corresponding Author:
E-mail: purushotham68@gmail.com

chills, the solidification conditions are altered and so are the casting properties [9-11]. The ability of the chill to extract heat from the molten metal during freezing of the casting is dependent on the size of the chill and thermo-physical properties of the chill material. In other words, the capacity of the chill to absorb heat from the casting is taken as a measure of its efficiency. The volumetric heat capacity,which takes into account the volume, the specific heat, and the density of the chill material has been identified as an important parameter in evaluating the efficiency of the chill and the corrosion resistance of the materials [12-16].

It has been found by certain researchers that the chilling process adopted in casting of composites helps in improving the quality of the castings. Even the shrinkage encountered during solidification can be eliminated by incorporating chills at strategic locations in the mold. Hence, in this study, chills have been used in the casting of composites.

2. EXPERIMENTAL DETAILS

2.1. Material Selection

The metal matrix material was selected available pure nickel base alloy (monel metal). The chemical composition of the matrix is given in Table 1. The properties of matrix alloy and the reinforcement (M35-1 Ni alloy) are as shown in Table 2. The reinforcement was pure SiO_2 of particles size 40-150 µm. Induction method was used for the preparation of the composite (Figures 1-3).

3. PREPARATION OF THE COMPOSITE

The nickel-based alloy/fused SiO_2 metal matrix composite was manufactured by utilizing the induction furnace along with stirrer for varying the percentage of reinforcing particles starting from 3 wt. % to 12 wt. % in steps of 3 wt. %. This technique is the most practical to create the composite ingredients. The matrix was initially superheated over its melting temperature (1560°C) and preheated SiO_2 (600°C) particulates included in the liquid metal and the liquid metal was blended appropriately. The melt at 1560°C was filled with sand molds. The molds for the plate sort of moldings of size 225 mm × 50 mm × 25 mm (American Foundry Men Society standard) were prepared utilizing silica sand with 5% bentonite as the binder and 5% moisture and finally dried. These castings were cooled from one end by distinctive metallic and non-metallic chill blocks set in the mold.

4. TESTING OF COMPOSITES

4.1. Corrosion Test

Electrochemical measurements were carried out using an electrochemical workstation, (CH600D-series, U.S. Model with CH instrument beta software). The electrochemical cell used was a conventional three-electrode compartment having glass cell with a platinum counter electrode and a saturated calomel

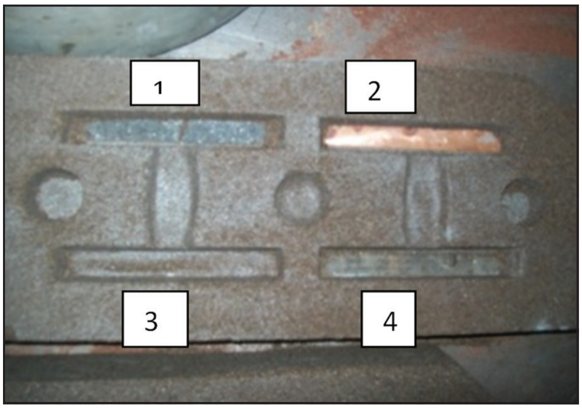

Figure 1: Chills arrangement (1) SiC chill, (2) Cu chill, (3) MS chill, (4) without chill.

Figure 2: Represents the nickel alloy, fused silica, induction furnace, mechanical stirrer, and casted composite specimens. (a) Pure nickel planks, (b) fused silica, (c) Induction furnace, (d) mechanical stirrer, (e) casted specimens.

Table 1: Composition of nickel alloy (M-35-1).

Element	**Ni**	**Cu**	**Fe**	**C**	**Mn**	**Si**	**P**
Composition in wt. %	Bal	26.6	0.513	0.196	3.02	0.8	0.0232
Element	S	Cr	Co	Al	Ti	Sn	Pb
Composition in wt. %	0.0027	0.0252	0.0826	0.112	0.121	0.0237	0.0753

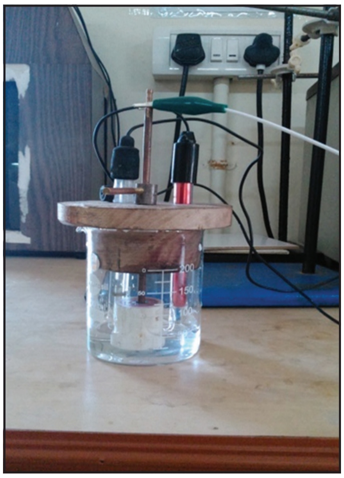

Figure 3: Tafel Polarization setup.

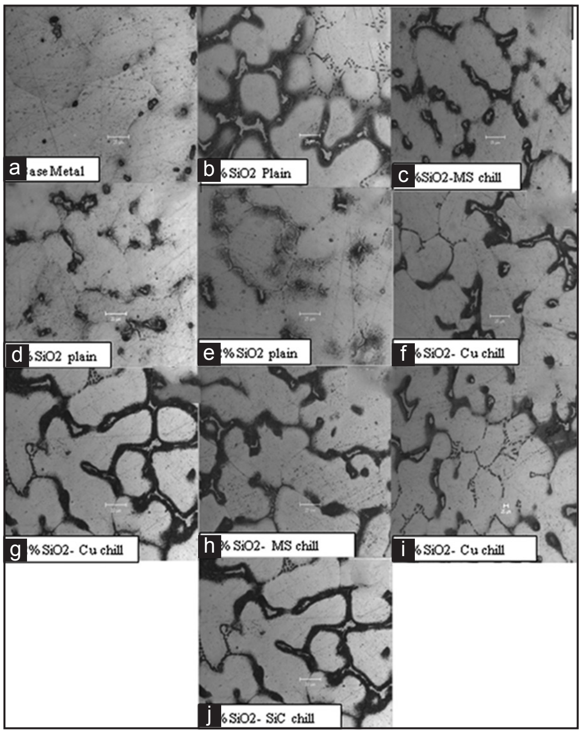

Figure 4: (a-j) Microstructural studies of base metal, with different weight % of SiO_2 and with different chills.

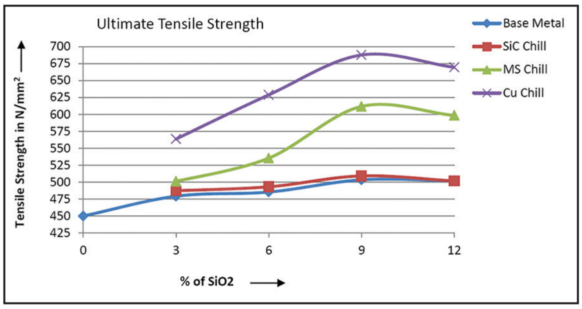

Figure 5: Tensile strength values of nickel-based composites with different SiO_2 percentages cast under the influence of different chills.

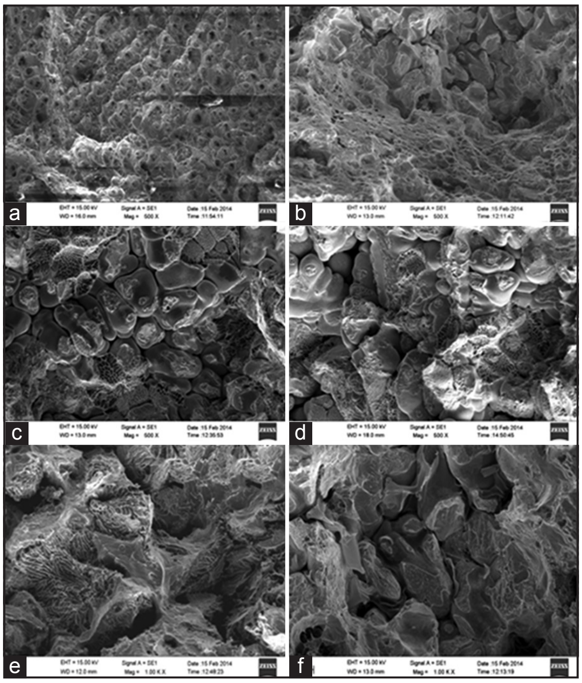

Figure 6: Scanning electron microscope (SEM) photographs of different wt. % of SiO_2 with different chills. ([a] The SEM photograph of base metal (×500), [b] The SEM photograph of 3 wt. % SiO_2 (without chill), [c] the SEM photograph of 6 wt. % SiO_2 (without chill), [d] the SEM photograph of 9 wt. % SiO_2 (without chill), [e] the SEM photograph of 6 wt. % SiO_2- SiC chill, [f] the SEM photograph of 9 wt. % SiO_2-Cu chill).

electrode (SCE) as reference. The working electrode was made up of monel metal. All the values of potential were with reference to the SCE as shown in Figure 3.

5. RESULTS AND DISCUSSIONS

5.1. Microstructural Studies

The microstructures of fabricated as deposited samples were observed to be in agreement with those predicted microstructures. It is witnessed from the microstructural revisions that the structure was observed to be close packed dendritic with only primary dendrite arms visible and with no evidence of precipitation or grain boundary segregation of solute atoms. Moreover, the dispersoid is spread homogeneously, and this is predominantly because of stirring and density differences. Closeness is flawless 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 because of the influence of chilling (Figures 4-6).

5.2. Mechanical Properties - Ultimate Tensile Strength

From the present results, it is cleared that the dispersoid content is increases, tensile strength is also increases

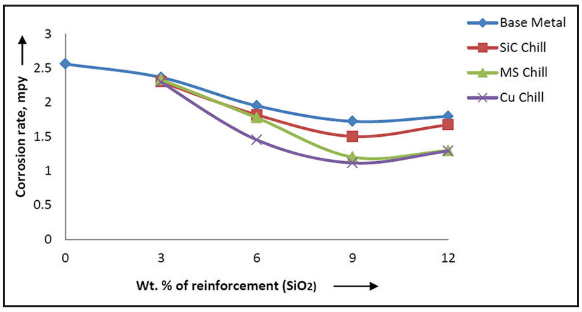

Figure 7: Plot of corrosion rate versus wt. % of SiO_2 for the composites cast under the influence of different chills.

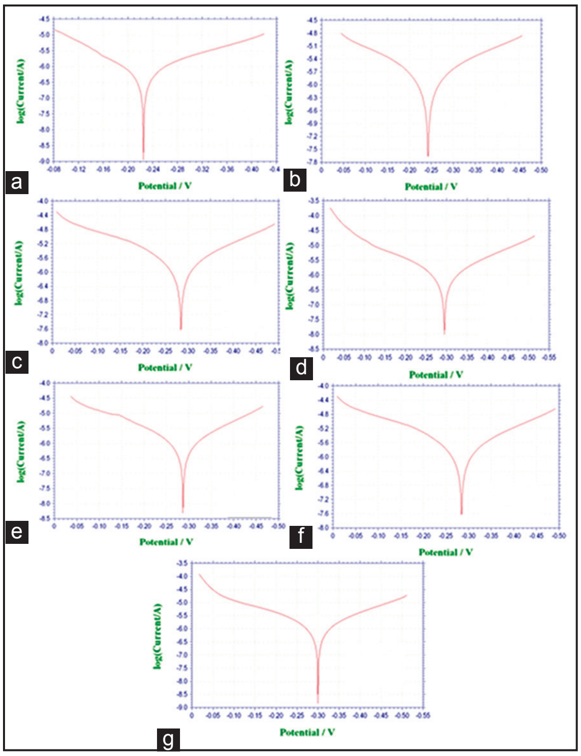

Figure 8: The graph of current versus potential of corrosion rate for different wt. % SiO_2 of nickel alloy for different chills ([a] Graph of current v/s potential of corrosion rate for the base metal of nickel alloy, [b] graph of current v/s potential of corrosion rate for 3 wt. % SiO_2 of nickel alloy for mild steel chill, [c] graph of current v/s potential of corrosion rate for 6 wt. % SiO_2 of nickel alloy for copper chill, [d] graph of current v/s potential of corrosion rate for 9 wt. % SiO_2 of nickel alloy for SiC chill, [e] graph of current v/s potential of corrosion rate for 12 wt. % SiO_2 of nickel alloy for copper chill, [f] graph of current v/s potential of corrosion rate for 12 wt. % SiO_2 of nickel alloy for MS chill, [g] graph of current v/s potential of corrosion rate for 12 wt. % SiO_2 of nickel alloy for SiC chill).

up to 9% addition of reinforcement since fused SiO_2 is a hard ceramic embedded in nickel matrix. After addition of further reinforcement, the tensile strength

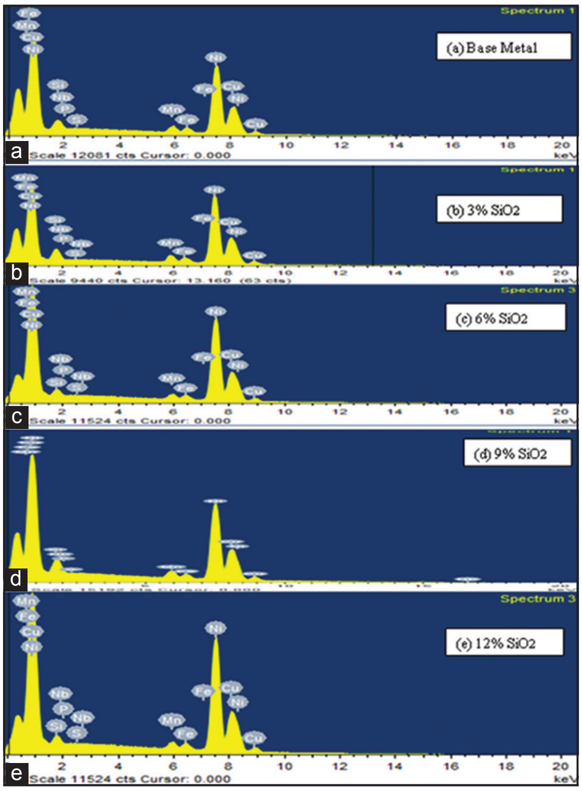

Figure 9: (a-e) The chemical composition and constituents of nickel alloy.

gradually decreases from 9% to 12% addition i.e., an increase 3% of SiO_2 wt.

5.3. Scanning Electron Micrographs (SEM) of Fractured Surfaces

To understand the mode of fracture for the specimens failed under the tensile test, fractographic analysis was carried out on the composite material developed. The fractographs obtained using SEM indicates as shown in Figure 6a-f.

The fractomicrographs of 25 mm thickness chill cast with Ni/SiO_2 containing 3 wt. %, 6 wt. %, 9 wt. % and 12 wt. % SiO_2 are shown from figures. Figures show respectable closeness sandwiched between the matrix and the reinforcement. It was observed from the micro photographs that the fractured surfaces on the dispersoid content increase the mode of fracture shifts from ductile to brittle. From Figure 3 wt. % shows shallow dipped surface indicating ductile fracture. Figure 6 wt. % shows the transforming from ductile to brittle indicating a bi-model type of fracture and figure 9 wt. % shows a cleavage type of fracture.

5.4. Corrosion Test

5.4.1. Corrosion test results

Figure 7 shows that the corrosion resistance is impacted by the impact of the distinctive chills and in addition

Table 2: Properties of matrix alloy and the reinforcement (M35-1 Ni alloy).

Property	Nickel alloy (matrix alloy)	Silica (reinforcement)
Density	8.908 g/cc	2.78 g/cc
Tensile strength	450 MPa	48.3 MPa
Hardness	638 MPa	Rc: 89
Crystal structure	FCC	-
Melting point	1455°C	1650°C
Thermal conductivity	1.38 W/m.°K	1.3 W/m.°K
Coefficient of thermal expansion	-	0.4×10^{-6}/k

Table 3: EDX test results of major chemical composition for nickel base alloys.

Description	% of SiO_2	% of nickel	% of copper
Base metal	0.83	62	30
3% SiO_2-plain	2.39	67	26
6% SiO_2-plain	5.63	62	27
9% SiO_2-plain	8.21	60	26
12% SiO_2-plain	11.07	61	22

EDX: Energy dispersive X-ray

the dispersoid content (Figures 7 and 8). Corrosion resistance is expanded with expansion of the dispersoid content and in addition chilling rate. The corrosion rate of the unreinforced matrix alloy (corrosion rate=2.563 mpy) is higher than that of the composites because in the former there is no reinforcement phase and the matrix alloy does not have much corrosion resistance to the acid media. Silica is a hard ceramic that stays latent and is itself unpretentious by the acidic media during the tests. The inert fused silica particulates are also not expected to affect electrochemically the corrosion mechanism of the composite. It is likewise seen from the chart that the corrosion rate is reduced as the dispersoid is built even up to 12 wt. % for composites cast utilizing distinctive chills. It was found from the experimental result that the corrosion resistance of the composite increases by 56% with an increase in the dispersoid content up to 9 wt. % for copper chill.

5.5. Chemical Composition by Energy Dispersive X-ray (EDX) Test

The dispersion content present in the composite can be analyzed through EDX test and the presence of silica are as shown in Table 3, and from Figure 9a-e.

6. CONCLUSIONS

1. Nickel-based metal matrix composite can be casted successfully from a conventional electric induction furnace.
2. Different chill material and the dispersoid content, however, do significantly affect the physical and chemical properties of the composites.
3. Microstructure of the chilled composites is finer than that of unchilled matrix alloy with uniform distribution of SiO_2 particles. Strong interfacial bond was observed with no agglomeration between the matrix and the dispersoid.
4. It was observed from the microphotographs that the fractured surfaces on the dispersoid content increase the mode of fracture shifts from ductile to brittle. From Figure 3 wt. % shows shallow dipped surface indicating ductile fracture. Figure 6 wt. % shows the transforming from ductile to brittle indicating a bi-model type of fracture and Figure 9 wt. % shows a cleavage type of fracture.
5. The strength of the chilled MMC is superior to those of the unchilled matrix alloy. It was found that these properties increase with an increase in the dispersoid content up to 9 wt. % and then gradually decreasing the strength.
6. It is clearly indicated that the dispersoid is uniformly distributed in the matrix alloy by EDX test.
7. Chill material and the dispersoid content, however, do significantly affect the corrosion properties of the composites. It was found that the corrosion resistance increase with an increase in the dispersoid content up to 9 wt. %. Hence, this property of corrosion resistance is most suitable for marine applications.

7. REFERENCES

1. J. Hemanth, (2009) Cryo effect during solidification on the tribological of Aluminium- alloy/glass (SiO_2) MMC, ***Journal of Composite Materials***, **43(06):** 6.
2. P. K. Rohatgi, (1993) Metal matrix composites, ***Defense Science Journal***, **43(4):** 323-349.
3. C. A. I. Bin, T. A. N. Ye-fa, T. U. Yi-Qiang, W. A. N. Xiao-Long, T. A. N. Hua, (2011) Tribological properties of Ni-base alloy composite coating modified by both graphite and tiC particles, ***Science Direct***, **21:** 2426-2432.
4. M. Srivastava, A. Srinivasan, V. K. W. Grips, (2011) Influence of zirconica incorporation on the mechanical and chemical properties of Ni-Co alloys, ***American Journal of Material Science***, **1:** 113-122.
5. L. I. Jian-Liang, X. Dang-Sheng, (2007) Mechanical and friction properties of Al and titanium reinforced Ni-based self lubricating composite, ***Transaction of Non Ferrous Metal Society of China***, **17:** s105-s108.
6. K. R. Marikkannu, K. Amutha, G. P. Kalaignan, T. Vasudevan, (2004) Studies on Ni-Al electrocomposite coatings of over mildsteel substrate, ***International Symposium of Research Students on Material Science and Engineering***,

Dec 20-22, Chennai.
7. A. Erol, A. Yonetken, I. Yildiz, M. Erdogan, (2009) Fabrication of Ni MMC reinforced with SiO2 by microwave sintering, ***5th International Advance Technical Symposium,*** May 13-15.
8. K. Funatane, K. Kurasania, P. A. Fabiyi, M. F. Puz, (1994) Improved engine performance via use of Nickel ceramic composites (NCC coat), ***SAE International,*** **1(1):** 89-96.
9. Z. Lei, Z. Lixia, T. Xiaoyu, H. Peng, F. Jicai, (2011) Interfacial micro structure and mechanical properties of joining electroless nickel plated quartz fibres reinforced Silica composite to invar, ***Material and Design*****, 32:** 382-387.
10. K. A. Ragab, R. Abdel-Karim, S. Farag, S. M. El-Raghy, H. A. Ahmed, (2010) Influence of SiC, SiO_2 and graphite on corrosive wear of bronze composites subjected to acid rain, ***Tribology International*****, 43:** 594-601.
11. J. Mendoza-Canales, J. Martin-Cruz, (2008) Corrosion behavior of titanium and Ni-based alloys in HCl and HCl+H_2S environments, ***International Journal of Electro Chemical Science*****, 3:** 346-355.
12. M. S. El-Sayed, A. H. Seikh, (2015) Effect of exposure period and temp. On the corrosion of incoloy alloy 800^{TM} in hydrochloric acid pickling solutions, ***International Journal of Electrochemical Science*****, 10:** 1843-1854.
13. B. Sabbaghzadeh, R. Parvizi, A. Davoodi, (2014) Corrosion evaluation of multi-pass welded nickel-aluminium bronze alloy in 3.5% sodium chloride solution: A restorative application of gas tungssten arc welding process, ***Materials and Design*****, 58:** 346-356.
14. Y. Hou, L. Yunping, C. Zhang, A. Chiba, (2014) Effect of cold working on corrosion resistance of Co-modified Ni-16Cr-15Mo alloy in hydrofluoric acid solution, ***Corrosion Science,*** **89:** 258-267.
15. C. DellaCorte (2010), Nickel-titanium alloys: Corrosion proof alloys for space bearing, components and mechanism applications, ***NASA Kennedy Space Center***, May 12-14.
16. G. Brunoro, A. Frignani, A. Colledan, C. Chiavari, (2003) Organic films for protection of copper and bronze against acid rain corrosion, ***Corrosion Science*****, 45:** 2219-2231.

***Bibliographical Sketch**

Prof. G. Purushotham currently serves as Professor in the department of Aeronautical Engineering at Mangalore Institute of Technology & Engineering, Moodbidri, Karnataka, India. I completed my research work on Material Science and Engineering at VTU Belagavi. My areas of interests are Material Science and Metallurgy, Composite materials, manufacturing Technology etc.