A Review on Corrosion Behavior of Nickel Matrix Composites

B. K. Anil Kumar¹, M. G. Ananthaprasad², K. Gopala Krishna³

¹Research Scholar, Department of Mechanical Engineering, Jain University, Bangalore-562 112
²Dean / Professor, School Of Engineering, Dayananda Sagar University, Bangalore-560068
³Associate Dean / Professor, Centre for Emerging technology, Jain University, Bangalore-562 112

Abstract—Nickel in elemental form or alloyed with other metals or materials has made significant contribution to our present day society. Nickel and nickel alloys are the class of advanced material that are are identified as candidate materials for marine applications and vitally important to aerospace, automotive industries because of their ability to withstand a wide variety of severe operating conditions involving high temperatures, corrosive environments, high stresses, strength, toughness, metallurgical stability, and combinations of these factors. The demand for such functional material to provide high performance has resulted in continuous attempts being made particularly in areas of alloy design and the use of novel processing techniques to develop composites or hybrid materials as serious competitors to the traditional engineering alloys. Also a simple and cost effective method for manufacturing of the composites is very essential for expanding their application. Metal matrix composites (MMCs) offer designers many benefits as they are particularly suited for applications requiring good strength at high temperature, good structural rigidity, excellent corrosion resistance, and light weight. This paper presents a review on the corrosion behaviour of Nickel matrix composites containing single and multiple reinforcement.

Keywords—corrosion, corrosion testing, Nickel alloy, Nickel matrix Composites, reinforcement, wear.

I. INTRODUCTION

Many of our modern technologies require materials with unusual combinations of properties that cannot be met by the conventional metal alloys, ceramics, and polymeric materials. This is especially true for materials that are needed for aerospace, underwater, and transportation applications. In order to achieve better performance in engineering materials, there is an increasing trend towards using composite materials. The increase in demand for low cost, lightweight, high performance, stiff, quality and strong materials has led to the development of composites which is having a number of advantages over conventional monolithic materials and alloys.

Composite materials are defined as macroscopic level mixtures of non-soluble constituents with two or more distinct compositions.

One of the materials that ensure the connection is known as the matrix and the other which imparts resistance is called the reinforcement. The reinforcement presents itself generally in the form of particles, short fibres or long fibres. By combining different materials, it is possible to develop a new material with superior properties. The combination of the constituent materials is determined from the specific application that is intended and the relative importance on several factors such as resistance to corrosion, rigidity, weight, fatigue, thermal expansion. Today, lot of research work is going on in the discovery of Metal matrix composite (MMC’s) globally to improve the corrosion resistant properties. Recently, MMC’s have gone through a transition that MMC’s are most promising in achieving excellent mechanical properties over conventional metals and alloys that are considered as potential engineering materials for various aerospace, marine and automotive applications, but relatively little information is available about the cast MMC corrosion behavior.

Nickel-based alloy is widely used in the chemical plant, nuclear power plant, oilfield and some corrosive environments due to its favorable properties such as strength and ductility over a wide range of service temperature and, especially, its superior corrosion resistance. Such excellent properties make it appropriate for the first choice of some important components in the aggressive environments [1—3]. Nickel base alloys provide outstanding resistance to specific chemicals, and some are extremely versatile and able to handle complex process and waste streams. In particular, the versatile alloys are much less subject than stainless steels to stress corrosion cracking pitting, and crevice attack in hot chloride bearing solutions. Nickel alloys are among the few materials able to withstand hot hydrofluoric acid, a chemical that is very corrosive to the reactive metals (titanium, zirconium, and niobium). Austenitic nickel base alloys appear to be a promising alternative to austenitic stainless steels because of their better corrosion resistance, thermal conductivity and mechanical properties. But the issue of Nickel based alloy corrosion poses an extreme concern in any design.
One of the first questions a designer must address when analyzing a Nickel and nickel based matrix composite material for marine application is whether the material selected will be subjected to a corrosive attack during service. It is important for designers to understand that there are several different types of corrosion including galvanic corrosion, concentration-cell corrosion, stress corrosion, fretting corrosion, pitting, and oxidation and to choose the right alloy.

Corrosion of nickel matrix composites has been studied extensively by several authors. Yagodkina et al. observed either the accelerating or inhibiting effect of nickel corrosion depending on the diamond particle size. The authors concluded that differences in the corrosion rate were due to a different crystallographic structure of the nickel matrix. Bapu et al., reported that corrosion resistance of Ni-BN composites decreased with BN content in the metal. The physicochemical properties of composite electroplates like the hardness, wear resistance, and corrosion resistance depend on the composition and structure of matrix, the amount and the bulk distribution of the dispersed particles of a filler, which are determined by the electrolysis conditions [4–8], and the mode of subsequent heat treatment [9]. Nickel electro composites assume ever most importance in engineering applications.

No other metal matrix composite has found so widely differing applications as nickel matrix composites. Nickel matrix composites containing particles like oxides, carbides, nitrides or diamond have been developed for their improved wear resistance and dispersion strengthening [10–12]. Sulfides and organic polymer particles such as PTFE co deposited nickel composites possess anti-friction properties [13]. Production of heat- and oxidation-resistant coatings by the inter diffusion of co deposited particles were also reported by several authors [15–16]. This paper presents a review on the corrosion behavior of Nickel matrix composites produced by different methods containing single and multiple reinforcement.

II. CORROSION BEHAVIOR’S

Yagodkina et al., (1997) observed that either the accelerating or inhibiting effect of nickel corrosion depending on the diamond particle size. The authors have revealed that differences in the corrosion rate were due to a different crystallographic structure of the nickel matrix. Also, the proper control of the electrodeposition parameters is a must in order to obtain the best microhardness and corrosion behavior of such nanocomposite coating.

The authors have concluded that including diamond nanoparticles into a metallic matrix can take advantage of the diamond properties, especially of its hardness and inertness in many chemical media which will improve the corrosion resistant property.

Mykolas et al., (2001) studied the corrosion of nickel metal matrix composites containing B₄C, Al₂O₃ and SiC particles by corrosion test in neutral and acid salt fog, and also investigated the electrochemical behavior of MMC in neutral and acid solution by means of voltammetry and impedance spectroscopy. Al₂O₃ inhibited corrosion in the acid environment and did not affect in neutral one. The authors have revealed from volumetric measurements that an increased corrosion susceptibility of Ni-B₄C composites due to the acceleration of the partial anodic reaction, which is more favored on the metal particle interface than on the rest of the surface. In neutral salt fog corrosion rates of Ni-Al₂O₃ and Ni-SiC did not differ significantly from those of pure nickel, whereas Ni-B₄C exhibited significantly higher corrosion susceptibility. In the acid environment B₄C also accelerated corrosion, whereas Al₂O₃ tended to inhibit it. The authors have concluded that the corrosion susceptibility of Ni-B₄C composite increased due to acceleration of a partial anodic reaction of the corrosion process. The accelerated anodic dissolution of nickel was accounted for by a higher activity of the metal/particle interface than that of the metal/passive layer interface.

G.N.K. Ramesh Bapu et al., (2002) studied corrosion behavior of the Nickel–mica (Ni–mica) composite in 5% sodium chloride (NaCl) solution. The authors observed that the Ni–mica composites offer improved protection to steel against corrosion in 5% NaCl solution. The corrosion current also decreased with incorporation of mica into nickel matrix compared to steel. Increase in mica content from 6 to 16% decreased the corrosion current and offered about three to four times more protection to steel substrate. Thus, authors concluded the Ni–mica composite hinders the diffusion of chloride ions through the composite thereby enhancing the corrosion resistance.

Pazman et al., investigated the formation of intermetallic phases between Nickel and Al-SiC composites and the sintering temperature of 580°C which favoured the diffusion of Nickel into matrix to improve the corrosion resistant property. Burak Dikici et al., [19] have studied the influence of Nickel on the corrosion resistance of Al-SiC composite prepared by liquid processing. The authors revealed that nickel coated composites have not showed significant improvement in corrosion resistance of the composite in neutral medium.
According to Liang-Guang Chen and Su-Jien Lin [20], the Nickel coated SiC exhibited low interfacial strength values for Fiber reinforced 7075 Aluminium composites. L.B. Li et al. [21], studied that electroless nickel coated Silicon carbide/Aluminium composites in alkaline medium increased the microhardness and adhesion. The authors have not claimed corrosion resistance in alkaline bath. However electroless coated reinforcement enhanced the adhesion and diffusibility between heavier particles, there is lack of information available on the improvement of interfacial strength and microhardness by coating process.

Meenu Srivastava, et al., (2011) studied the corrosion and wear destroy in multibillion dollar range annually. Modern high performance components which are subjected to extreme temperatures and mechanical stress require surface protection against high temperature and mechanical wear and tear. A highly versatile and low cost technique is selected by authors to apply protective coatings, one such technique is electroplating. Composite electroplating involves the co-deposition of insoluble metallic or non-metallic compounds in a metal or alloy matrix. Such composite coating features the properties of both the matrix and the dispersed phase. The coatings are called as metal matrix composites (MMC) when the matrix involved is a metal. Composite coatings comprising of various dispersed phases like SiC, Si₃N₄, Al₂O₃, CeO₂, TiO₂, YSZ etc. have been developed for diverse applications. The composite system considered in the study comprises of Ni–Co alloy as the matrix. The benefit of choosing Ni-Co alloy as matrix lies in the fact that alloying of Ni with Co strengthens it by forming a solid solution which helps to improve wear, corrosion resistance and also improves the high temperature properties. The authors have chosen zirconia ZrO₂ has dispersed phase, as it is known to possess excellent properties such as the effect of incorporation of ZrO₂ in Ni matrix has been extensively reported. Reddy et al have reinforced tetragonal ZrO₂ in Ni matrix by pulsed electrodeposition. The authors have reported the 16% increase in microhardness of the composite. The composite on annealing (50-200°C) showed an increase in the microhardness followed by a substantial decrease up to 300°C. Effect of heat treatment on the incorporation of ZrO₂ in Ni-Co matrix has not been studied much. Zhang et al. have reported brush plating of Ni-Co – ZrO₂ composite coating to repair the wear surface of the die casting dies of H13. The coating improved the surface hardness, wear resistance and oxygen resistance of dies. The study was aimed at incorporating ZrO₂ nanoparticles in Ni-Co alloy matrices by electrodeposition method, and its influence on the thermal, mechanical and chemical properties.

J.F. Flores et al., (2011) assessed the corrosion and erosion-corrosion (EC) processes of four metal-matrix composites (MMCs) in a simulated cooling water environment. The MMCs consisted of two Ni-base and two Fe-base matrices alloyed with different concentrations of chromium, molybdenum, boron, silicon, and carbon; the matrices were reinforced with tungsten carbide (WC) particles. The authors obtained Ni base MMCs using two variations of Ni-Cr (nickel-chromium) matrices, one with a lower concentration of alloying elements (WC-NiCrBSi) and one with additional alloying elements such as molybdenum (Mo) and tungsten (W), (WC-NiCrMoWB). The corrosion behavior has been investigated by authors using a combination of potentiostatic polarization and post-tests surface analysis. At static conditions it was found that as the temperature increased, there was a transition from a homogeneous corrosion of the matrix to an interfacial corrosion mechanism. The authors concluded Ni based MMCs showed a better corrosion resistance and a highly alloyed matrix will not significantly improve MMCs corrosion resistance. The corrosion behavior and degradation mechanisms of the MMCs in static conditions were linked to the corrosion resistance of the matrix phase and the volume fraction of secondary phases embedded in the matrix. Changes in the slope of the Arrhenius plot (Fig 1) and microscopic analysis (Fig 2) suggesting the existence of a transition zone from a more general corrosion process to a severe selective corrosion process which took place mainly at the interfacial zones.

The MMCs studied by J.F. Flores et al., research work presented Changes in the corrosion extent and control rate explained by analyzing the Arrhenius plots (Fig. 1a, b) and the surface of the MMCs after the potentiostatic tests (Fig. 2). For instance, two slopes were observed in the Arrhenius plot of the WC-FeCr and WC-FeCrC MMCs (Fig. 2a).
Jiang Xu et al., (2009) studied the corrosion behavior of nano-particle-reinforced Ni matrix composite by duplex surface treatment consisted of Ni/nano-SiC and Ni/nano-SiO2 pre deposited by brush plating and a subsequent surface alloying with Ni–Cr–Mo–Cu by double glow process of the substrate. The weight loss rate studies suggested by authors that the highly dispersive nano-SiO2 particles were helpful to improve the erosion–corrosion resistance of composite alloying layer, whereas the carbides and silicide phase were deleterious to that of composite alloying layer due to the fact that preferential removal of matrix around the precipitated phase takes place by the chemical attack of aggressive medium.

The authors concluded in the results that the increase of the impact velocity had significant influence on the current density of composite alloying layer with brush plating Ni/nano-SiC particles interlayer obtained under flowing condition at a potential of 200mV. The results of potentiodynamic polarization indicated that, with increasing impact velocity under slurry flow conditions, the corrosion potentials of test materials decreased and the corrosion current densities of test materials increased. The corrosion resistance of composite alloying layer with brush plating Ni/nano-SiO2 particles interlayer was prominently superior to that of single alloying layer under slurry flow conditions; the corrosion resistance of composite alloying layer with brush plating Ni/nano-SiC particles interlayer was evidently lower than that of single alloying layer, but higher than that of 316L stainless steel under slurry flow conditions. The authors revealed the factor that can influence the nature of corrosion or erosion–corrosion mechanism of materials is pertinent to its microstructure characteristic and composition, including the type of reinforcement phase, the presence of an interfacial reaction product, precipitated phase within the matrix and concentration of corrosion resistant elements.

III. CONCLUSION

From the above review the corrosion behavior of Nickel based metal matrix composite leads to following conclusion:
Corrosion behavior of Ni-MMC studies and investigation conducted by several authors has been reviewed.
The electrochemical behavior of MMC investigation in neutral and acid solution have been reviewed
The incorporation of reinforcement into Nickel matrix alloy offer improved protection against corrosion.
Finally there is an immense potential, scope and opportunities for the researcher, in the field of corrosion resistant improvement of nickel matrix composites by cast method.

REFERENCES


