



Microstructural evolution and mechanical, and corrosion property evaluation of Cu–30Ni alloy formed by Direct Metal Deposition process

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ABSTRACT

In the current investigation Cu–30Ni alloy was successfully laser deposited on a rolled C71500 plate substrate by Direct Metal Deposition technology. The microstructural investigation of the clad was performed using optical and scanning electron microscopy. The phase and crystal structure analysis was performed using X-ray diffraction technique and transmission electron microscopy. The microstructure consisted of columnar and equiaxed dendrites with face centered cubic crystal structure. The dendrites grew epitaxially from the substrate and layer and bead boundaries. Dendrites' growth direction (001) and growth angle 60° was maintained in each layer. The average primary dendritic arm spacing at the bottom part of the layers was about 7.5 μm and average secondary dendritic arm spacing in the upper part of the layer varied between 2 μm and 4.5 μm. The lattice parameter of the identified phase was found to be longer than that reported in literature. The reported lattice parameters in literature are however from samples processed under equilibrium conditions. The microhardness of the clad was found to be less than the substrate but very consistent along the clad. Cu–30Ni clad specimen showed higher ultimate tensile strength but lower yield strength and percentage elongation as compared to the C71500 substrate. DMD Cu–30Ni clad/C71500 substrate specimen showed the worst mechanical properties. The corrosion resistance of the specimens was found to decrease in the order DMD Cu–30Ni clad, half-and-half DMD Cu–30Ni clad–C71500 substrate, and C71500 substrate.

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1. Introduction

Direct Metal Deposition (DMD), developed at the University of Michigan Ann Arbor, is a manufacturing process involving rapid solidification [1–3] and has been shown to minimize segregation of phases, extend solid solubility of alloying elements and produce fine grains which resulted in improving the mechanical properties of the materials [1–5]. DMD and several similar technologies namely, Directed Light Fabrication (DLF®) [6], Laser Engineered net Shaping (LENS®) [7], and Selective Laser Sintering (SLS®) [8] fall under a new group of manufacturing technologies called solid free form fabrication (SFF). SFF technologies are additive processes and include rapid prototyping (RP) and rapid manufacturing (RM) to produce near-net shape components from their computer aided design (CAD) files [2,9].

In DMD a CAD model is used for RP of the 3D object to be built. The entire 3D CAD model is divided into several 2-D par-

allel slices, each with a build height of approximately 25–33% of the beam diameter, and then a tool path is created to build each layer. The tool path data is converted into conventional CNC G and M codes and fed into the computer. RM then follows by focusing a high power laser beam onto a substrate to create a melt pool and simultaneously delivering fused pure metal (or alloy) powders into the melt pool through a specially designed coaxial nozzle, and forming a metallurgical bond with the substrate. The 3D object is created layer by layer by using a CNC machine that controls the part geometry and layer height according to the tool path data fed to the computer [10]. DMD has an edge over conventional manufacturing processes for low volume manufacturing of near-net shape components with complex geometries, coating surfaces, repairing parts, and building graded materials [2]. The closed loop optical feedback system employed in the DMD process reduces the manufacturing time, by eliminating intermediate steps from design to product [3]. The closely controlled process parameters during DMD also produces clad with uniform thickness and extremely fine and controlled microstructure [2–4]. However during DMD due to rapid solidification residual stresses are generated [11] which could result in cracks formation in the clad.

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Table 1

Cu–30Ni alloy powder composition (wt%).

Cu	Ni	Fe	Mn	Zn	C	Pb	P	S
Bal.	29.0–33.0	0.4–1.0	1.0	0.5 max	0.45	0.02 max	0.02 max	0.02 max

Copper based alloys generally have low strength but it has been shown that with different manufacturing techniques and alloying additions superior mechanical and corrosion resistance properties have been realized. Cupro–nickel alloys (primarily Cu–10Ni or Cu–30Ni, with compositions in approximate weight percentages) with some minor alloying additions are widely utilized as engineering materials for making condenser tubes of ships, heat exchangers of coastal power plants, desalination apparatuses and pipelines of desalination plants, boat hulls and several marine engineering applications because of their good corrosion resistance, good ductility, excellent electrical and thermal conductivity and superior anti fouling properties in seawater [12–15]. Minor iron additions, up to 1.8%, to cupro–nickel alloys have been reported to enhance the corrosion resistance of these alloys. It has been shown that the addition of iron both in and out of the copper–nickel solid solution increases the corrosion resistance in two ways. First in the solid solution, iron ions acts as an additional dopant to the protective Cu_2O film and enhances the stress corrosion resistance of the alloy. Second, complex iron phases formed on the protective Cu_2O film also helps in reducing the corrosion rate of these alloys [14–18]. However, excess precipitation of iron from the solid solution reduces the stress corrosion resistance of these alloys by reducing the iron content available for doping the protective Cu_2O film [14,18]. Iron addition of more than 2% also decreases the corrosion resistance of the cupro–nickel alloys [16]. Addition of other alloying additions in excess besides the usual iron addition up to 1.8% has been reported to be detrimental to the mechanical and corrosion properties of the alloys. Excess alloying additions cause severe segregation and coarsening of the microstructure in alloys produced by conventional casting [15,19]. The microstructure could be homogenized by subsequent annealing and has been shown to improve the mechanical and corrosion properties but are usually time consuming [12,13]. Cupro–nickel alloys produced by rapid solidification techniques such as, planar flow castings and melt spinning have been reported to have better corrosion resistance and mechanical properties compared to those produced by conventional casting. This has been attributed to fine grain size, homogeneous chemical composition and elimination of coarse segregated phases [15,19–21].

Since cupro–nickel alloys are primarily used as marine engineering material, failure of the equipments built with these alloys has been reported to occur primarily due to (i) stress corrosion caused by sulphide or ammonia polluted sea water, (ii) erosion corrosion caused by excessive fluid flow velocities and

(iii) crevice or pitting corrosion [1,12,16] in seawater. Corrosion resistances of cupro–nickel alloys are typically compared by (i) weight loss measurements as a function of time and (ii) electrochemical measurements to measure the potentiodynamic polarization of test specimens in artificial or natural seawater solutions [12–14,16,20,22]. During the test, seawater solutions were maintained at a slightly higher temperature and specimens were immersed either in a static bath [1] or in an agitated bath, either by moving the specimen at certain velocity or by aerating the solution to simulate the seawater corrosion [13,14,16,20].

The current research effort was undertaken to repair some high value C71500 components with a cupro–nickel alloy Cu–30Ni, by DMD process. Cupro–nickel alloys containing 10–30% nickel with some minor alloying additions produced by conventional manufacturing process and some rapid solidification processes have been well researched for their microstructural and mechanical and corrosion property evaluation. However, information on the microstructure and, mechanical and corrosion property of Cu–30Ni alloy deposited by DMD process is not available in open literature. In this investigation, microstructure evolution of Cu–30Ni alloy sample during DMD process and its mechanical and corrosion property evaluation has been reported.

2. Experimental

2.1. Materials

Gas atomized prealloyed Cu–30Ni powder (–100/+325 mesh) (Michigan Metals & Manufacturing Inc.) was used for preparing the test specimens Table 1 shows the chemical composition of the as-received powder. Fig. 1(a) shows as-received powder particles morphology and Fig. 1(b) shows particle microstructure. The powder particles were mostly spherical with an average particle size of 75 μm and 85% of the particles within the 60–120 μm range. Approximately 100 particles per micrograph were selected for measurements and always the largest diameter and the diameter in the direction perpendicular to the long axis were measured. The average powder particle porosity was found to be approximately 2%.

2.2. Specimen preparation

Fig. 2 shows the schematic of DMD process. DMD system consists of the laser generation system, the powder delivery system, feedback control system, and CNC motion stage [10]. The DMD process could be performed either in air or under controlled atmosphere. DMD samples for this investigation were prepared at POM using POM DMD 505 machine (developed by POM Group in collaboration with Trumpf Inc.) with a 5 kW CO_2 laser system. A combination of DMD processing parameters: laser power (W), processing speed (mm/min), and, powder feed rates (g/min) and 50% overlap between two adjoining passes, were used to prepare the test specimens. An inert gas mixture of helium and argon provided a protective environment to prevent

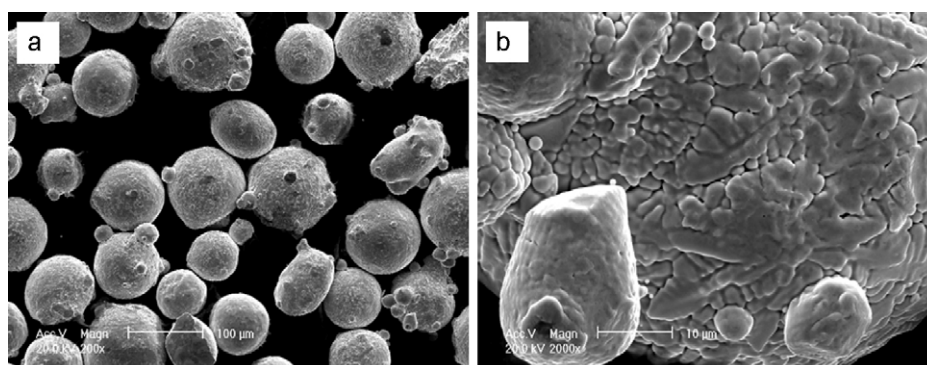


Fig. 1. SEM micrograph of Cu–30Ni alloy powder showing (a) particle morphology (b) particle microstructure.

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