Microstructural Investigation of Direct Metal Deposition of H13 Steel on High Strength Copper Substrate

M. Khalid Imran, S.H. Masood and Milan Brandt

***Abstract*- This paper presents an investigation on the microstructure analysis of a bimetallic component consisting of the steel powder deposited on the solid copper substrate using laser cladding technology, Direct Metal Deposition (DMD). Study includes the variation of formation of microstructures of copper particles and porosity in the laser cladded structure at various thicknesses. Results obtained from the Scanning Electron Microscope (SEM) and Energy Dispersive Spectroscopy (EDS) display a metallurgically sound and fully dense steel layer, where copper in rounded form was seen in the layer, which decreased with the increase of layer thickness. It is observed that porous holes also reduce with the increase of the thickness.**

***Index Terms:* Copper substrate, Direct Metal Deposition (DMD), Microstructure, Scanning Electron Microscope (SEM), Steel powder.**

I. INTRODUCTION

High thermal conductive materials are of great interest as mould material for both the casting and moulding industries. Studies that have been carried out to date to develop moulds with higher thermal conductivity (HTC) have concentrated on the manufacture of H13/Cu structures due to HTC of copper [1, 2]. This involves manufacturing 3D structures from a mixture of H13 and copper powders. The methods employed are based on the layer manufacturing technologies or rapid prototyping whereby structures are built layer by layer from a CAD file using a laser beam to sinter or melt the mixture of H13/Copper powder.

The technologies used in such methods are Selective Laser Sintering (SLS) [3] and Direct Metal Laser Remelting (DMLR), a derivative of SLS. In the SLS method, a layer of powder is first deposited on a support platform by a blade. A computer controlled laser beam sinters the layer, and then the processing platform moves down by one layer increment which sequentially deposits and sinters another layer. Both SLS and DMLR involve many different steps consequently, dimensional control of the final part can be difficult. The finished part is not fully dense and only simple shapes can be fabricated. Pogson et. al. [4] reported that the incorporation of copper into the tool steel during DMLR processing leads to the formation of a copper rich region around the prior austenite grain boundaries that will increase the risk of hot tearing and significantly weaken the material. In his experiment he also showed that the top of the processed layer was copper rich which is unfavourable for major applications. Another research group tried to deposit this powder layer using arc spray process and concluded with limited thickness and high porosity of the layer [5].

One major difficulty associated with steel and copper are that they are partially soluble and have got very different melting point. Moreover H13 tool steel is one of the difficult alloys for deposition due to residual stress accumulation as it forms martensitic structure during cooling.

Direct Metal Deposition (DMD) is a laser cladding process for fabricating fully functional metallic parts directly from CAD data, which involves the beam from a high power laser creating a melt pool on the surface of a solid substrate into which a metallic powder is injected [6-8]. The process allows fabrication of single material or multi-material parts. Thus bi-metallic components and tooling can be fabricated to advantage for various casting processes. Fig-1 shows a simple schematic diagram of the DMD process. The laser melts the powder and fuses it on to the substrate creating a fully dense, metallurgically sound bead. The width of a single bead depends on the diameter of the laser spot on the surface and is normally in the range 0.6-5 mm. By overlapping the beads, usually by 50%, a continuous layer is produced.

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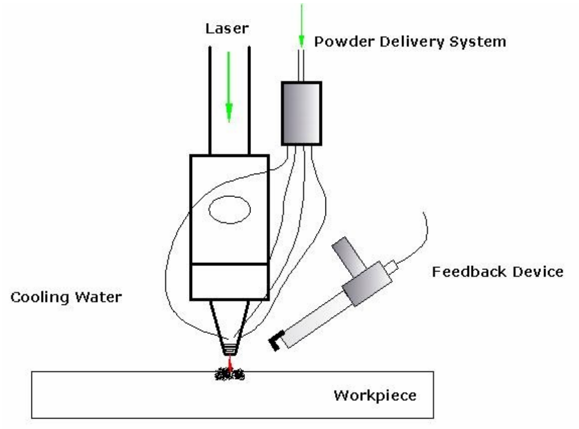


Fig-1: Schematic diagram of DMD process.

In this paper distributions of porosity and copper particles have been investigated for the DMD processed steel layer deposited on copper substrate. The results reveal a significant improvement in the processing of H13/Copper bimetallic structure.

II. EXPERIMENTAL WORK

Fig 2 shows a DMD 505 machine installed at Swinburne and supplied by Precision Optical Manufacturing (POM) Inc, USA. The machine has been used to deposit H13 tool steel powder on Moldmax substrate, which is a high strength beryllium copper. Steel powder was supplied by Sulzer Metco (Australia) Pty Ltd. and Moldmax was supplied by Bohler Uddeholm (Australia) Pty Ltd. The chemical compositions of Moldmax and H13 tool steel are given in the Table I & II respectably.

Fig-2: POM DMD 505 machine

Four samples of various thickness i.e. 0.6, 0.9, 1.5 and 2.1 mm of steel powder were produced on the moldmax substrate as shown in Fig 3. The DMD process parameters remained the same for all the samples during the whole deposition process. The power of the laser beam was 3000 watts, which produced a bead of 1.4 mm width and 0.3 mm height and each bead overlapped 50% with the previous one at every shot.

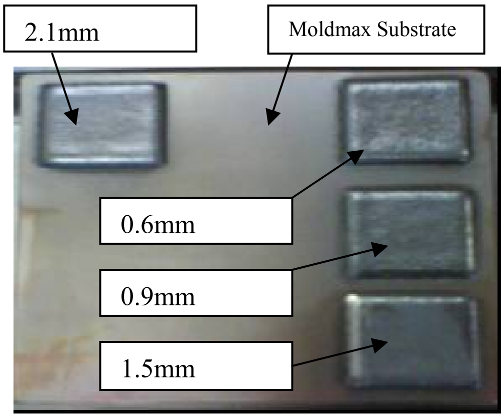


Fig-3: DMD deposited steel layers of different thicknesses on copper substrate

All the four samples are of 25×25 mm square surface area. The size of the steel powder particles were 90-106 micrometer. The samples were cut vertically to observe the microstructure and porosity distribution of both the cross section and top surface of the deposited layer and then polished with fine diamond polishing machine up to 1 micrometer. Finally the parts were etched using ferric chloride and 2% nital to allow a precise microstructural view of the surfaces. Fig 4 shows both the cross section and top surface of the polished and etched samples used for SEM and EDS analysis. All the SEM images were obtained using SUPRA 40 VP Scanning Electron Microscope manufactured by Carl Zeiss and EDS was done using SIRIUS 10/SUTW/SEM manufactured by Gresham Scientific Instruments. WINEDS software was also used for Energy Dispersive Spectroscopy.

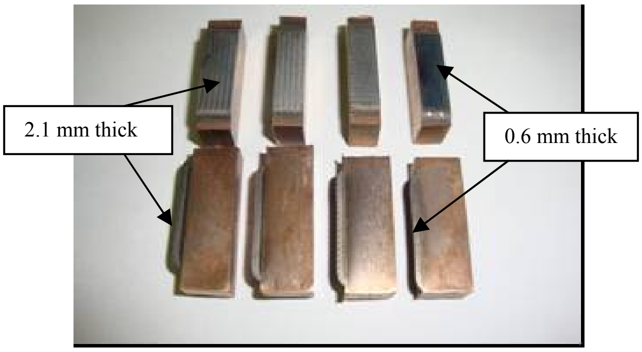


Fig-4: Cross sectional and top surfaces of the cut samples for SEM and EDS analysis in descending order of deposited steel thickness from left to right

Table-I: Chemical composition of Moldmax

Element	Be	Co + Ni	Cu
Chemical composition	1.9	0. 5	Balance

Table-II: Chemical composition of H13 tool steel

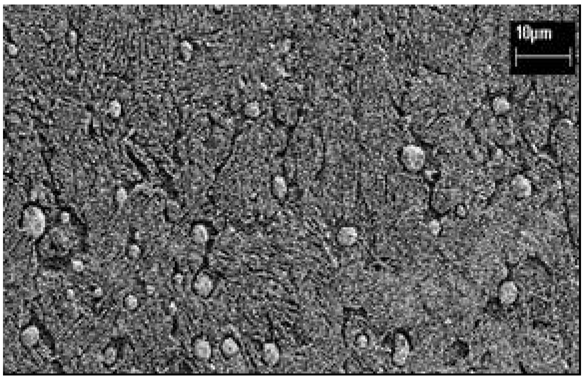
Element	C	Mn	Si	Cr	Mo	V	Fe
Chemical composition	0.35%	0.4%	1%	5%	1.5%	1%	Balance

III. RESULTS AND DISCUSSIONS

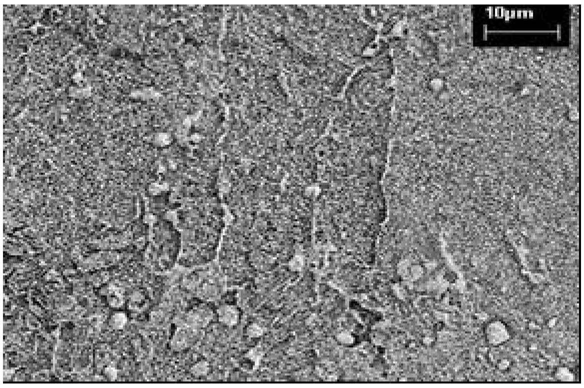
The first consideration of this experiment is to investigate the distribution of copper in the deposited layer. The Scanning Electron Microscopy images of cross section of the cladded layer shown in Fig-5 reveals the presence of copper as rounded particle surrounded by tool steel. Higher magnification of higher thick layer shown in Fig-6 gives the presence of very fine and discrete channels of copper in the layer. The sample with 0.6mm thickness of Fig-5 (a) shows large copper particles entrapped in steel. The size of the particles reduces with the increase of thickness distributing them as fine particles through the entire surface which is depicted in Fig-5 (b) and (c). The reason behind this is that in the DMD process, cladding is done layer by layer, where thickness of each layer depends on the process parameters. In this experiment steel was deposited with 0.3 mm thickness of each layer. In the first layer more copper comes in contact with molten steel and mixes in a large scale. But as the cladding goes on more, the copper content decreases, which is shown in Fig-7 where Energy Dispersive Spectroscopy (EDS) quantifies the contents at the top surfaces of 0.6 and 2.1 mm thick layers. Quantitative analysis of EDS shown in Table-III concludes that the copper at the top of 0.6 mm thick layer is much higher and it is reduced to very small percentage at the top of 2.1 mm thick layer. As a result of this continuous reduction of copper, while depositing consecutive layer, copper particles of the previous layer melts down and are distributed as fine particles in the next layer.

Table-III: Quantitative analysis of Cu presence

Layer thickness(mm)	0.6	0.9	1.5	2.1
Cu content (% wt)	5.91	3.08	1.24	0.6



(a)



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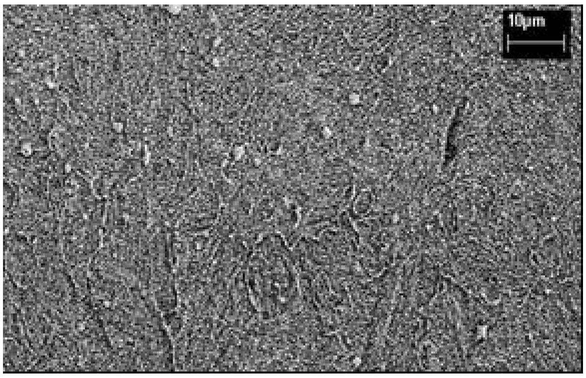


(c)

Fig-5: Scanning Electron Microscopy images of distribution of rounded shape Copper particles in different thicknesses of steel layers. (a) 0.6mm (b) 1.5mm and (c) 2.1mm

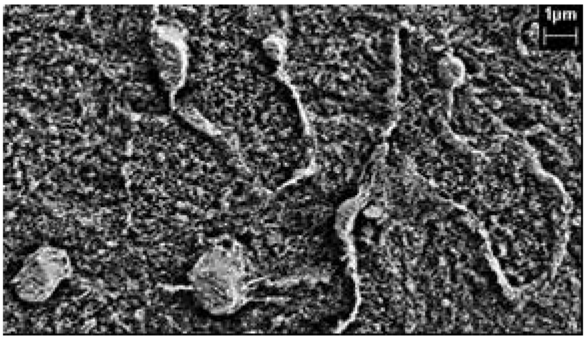
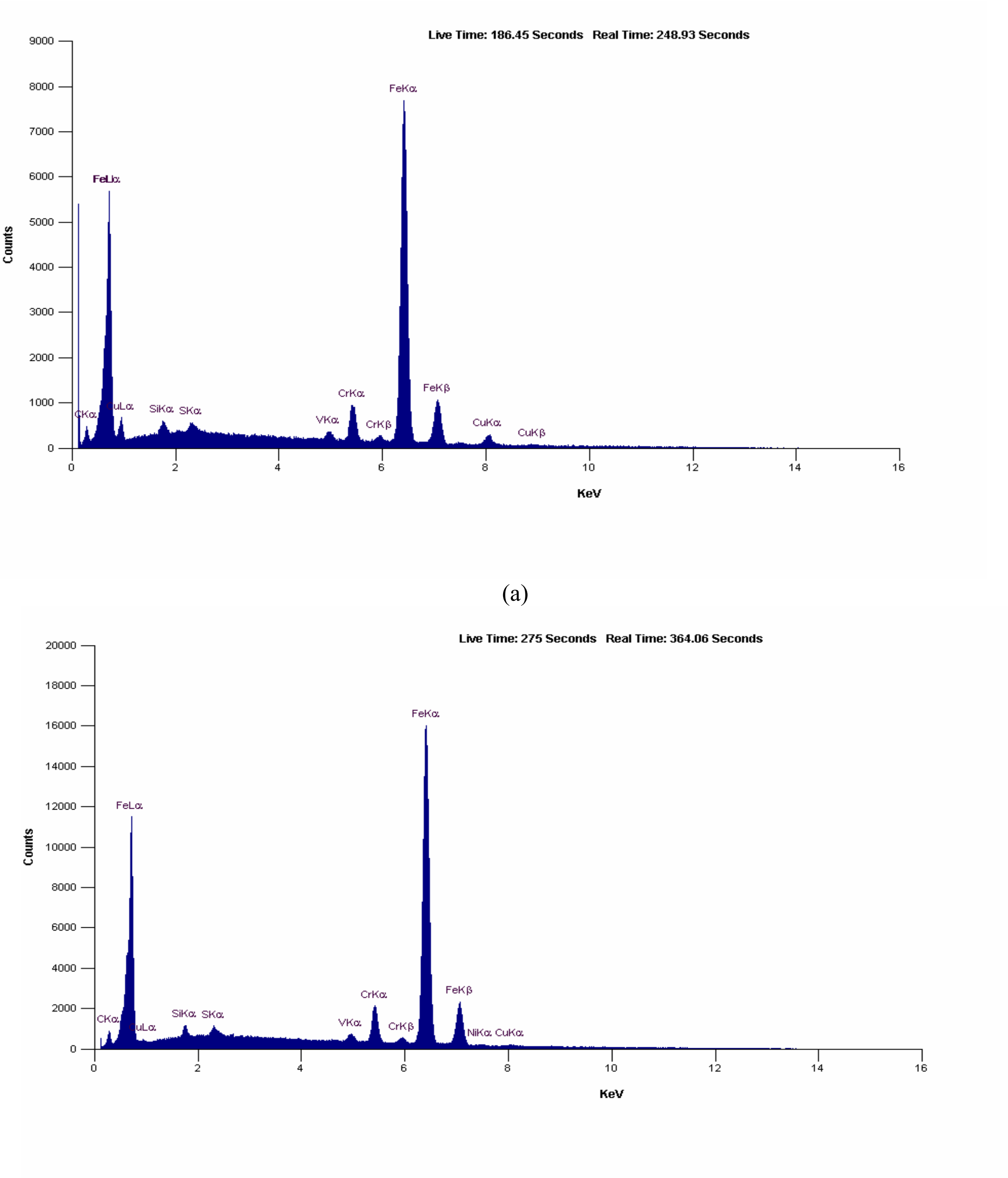


Fig-6: Higher magnified Scanning Electron Microscopy image of 2.1 mm thick layer showing discrete copper channels.



(a)

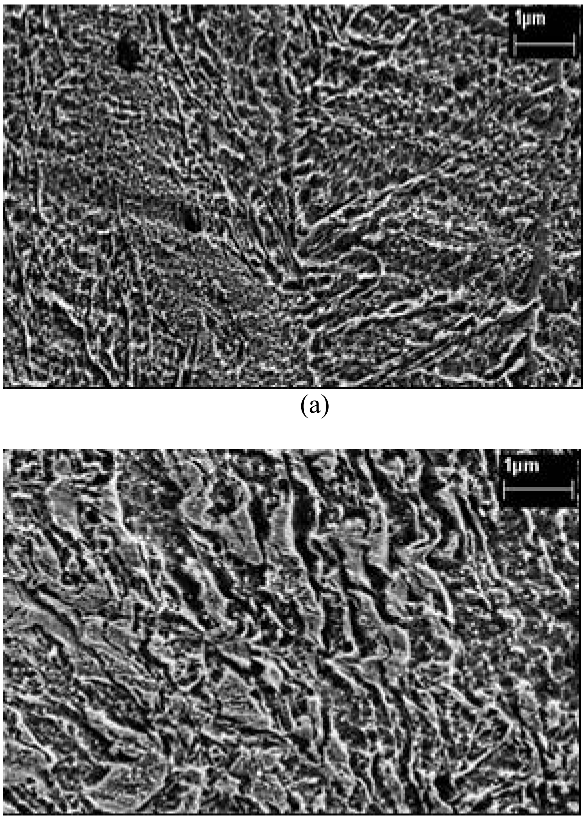
(b)

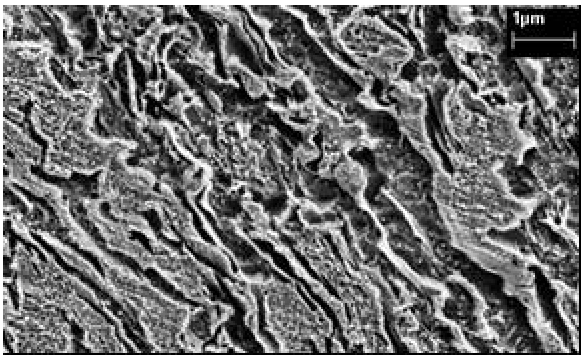
Fig-7: EDS image showing different elements on the top surfaces of the layers (a) 0.6 mm (b) 2.1 mm

Another observation of this experiment was to examine the porosity distribution in the formed surfaces. Fig-8 shows the nature of porosity in the deposited layers. Scanning Electron Microscopy identifies porous holes and less dense top surface on 0.6 mm thick layer. But the layers become more dense and porous holes free with the increase in deposited layer.

It probably happens due to higher thermal conductivity of copper, which transfers heat from top surface to other parts of the substrate while producing first layer causing insufficient melting pool for complete melting. When further deposition was done, this layer worked as a preheated surface for the next layer and so on to create complete melting pool and produced sound layers. This result was also observed visually at the time of producing the samples on the DMD machine.

Preheating the substrate before cladding first layer can be one solution to over come this difficulty.





(c)

Fig-8: Scanning Electron Microscopy images of top surfaces showing distribution of porosity (a) 0.6 mm (b) 0.9 mm and (c) 1.5 mm

IV. CONCLUSION

Bimetallic structure of H13 tool steel on copper substrate can be used for applications where quick heat transfer is needed and will provide high strength at the top surface as well. For instance it can be used in the high pressure die casting industries to transfer heat quickly to reduce cooling time at the same time offering resistance to the harsh environment at the cavity surface associated with die casting.

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