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An Approach towards Repairing Of Nimonic Alloy Component through Laser Based Layered Manufacturing Technique

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Abstract
In this work investigate has been done to identify the possibility of depositing a layer of Ni-Co-Cr powder mixture over an experimental block of Nimonic 263 alloy material in order to repair it by a 2 kW Ytterbium fiber laser. The various process parameters have been optimized to obtain the best quality deposition free of porosity and cracks. An optical microscopic study of the resulting microstructures of the substrate and deposited layers has been conducted. For further study SEM, analysis have also been carried out. The microhardness of deposited layer ranged from $HV_{0.05}306$ to $HV_{0.05}331$. The hardness decreases gradually from the top of the deposited layer to the substrate zone. The knowledge achieved in this study would help in taking decisions with regard to setting the parameters required for subsequent repair a Nimonic component through layered manufacturing.

Keywords: Laser, Direct Metal Laser Sintering, Nimonic 263, Repair.

I. Introduction

During the life of a component it may be subject to local impacts, corrosion, variable or regular thermal cycles and stresses, or other testing conditions with the potential to cause local defects or cracking. For example, cracks can be initiated in welds by mismatched creep properties, at geometric discontinuities in foundry goods on account of residual thermal stresses, and in turbine shafts and blades owing to high-cycle fatigue and corrosion. Fatigue and stress cracks are common initiators of failures that cause high-performance and high-value components to be discarded as useless. The development of ultrasonic techniques means that internal cracks can now be detected before failure occurs.

In the fields of mechanical engineering, metallurgical industry and petrochemical and electric power, a large number of components work in formidable conditions involving impact, abrasion, high-temperature and pressure, and are liable to breakdown. Fig.1 shows a cam which has been worn out and broken due to friction. If successful repairing cannot be carried out, the damaged components will have to be discarded and a significant loss will be caused.

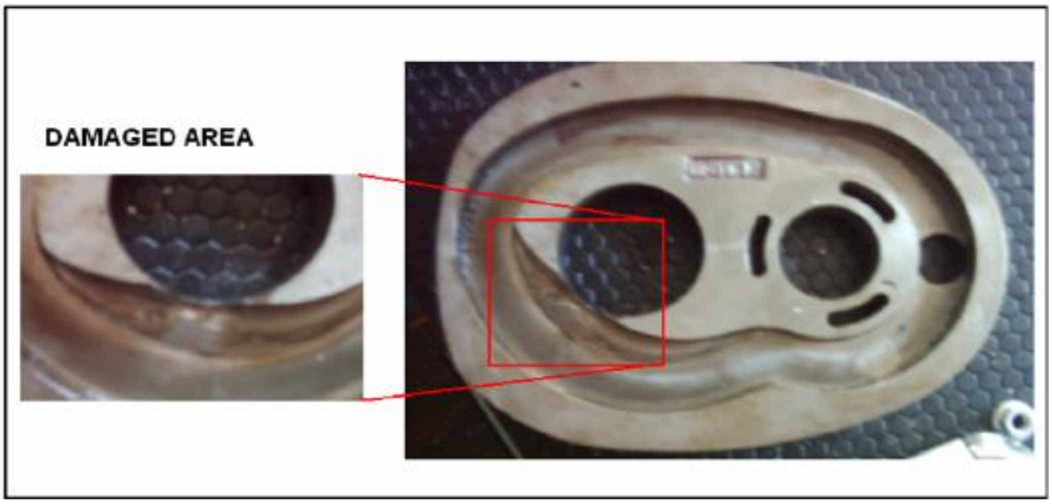

Fig.1: broken and worn out cam

Theoretically, any product that can be manufactured can be remanufactured. The cost of remanufactured goods is cheaper than a new part, and can be remanufactured multiple times, further extending its life. The ideal products for remanufacturing are those that are not likely to suffer from obsolescence, and those whose recoverable value is a high percentage of the price of the new product. Rebuilt engines, for instance, require only fifty percent of the energy and sixty-seven percent of the labor needed to produce a new engine. Hence, remanufacturing should be looked upon as a tool that can save and reuse resources to eventually boost a country's economy.

Conventional repairing methods presently adopted mainly include mechanical machining, brush-electroplate, deposited welding, TIG welding and thermal spraying (flame spraying and plasma spraying). Although, these methods have different advantages, there are still many drawbacks, such as being time-consuming and labor intensive, having limited thickness of deposition layers and machinable times, poor bonding strength, large amount of porosities and cracks, or significant heat injection and distortion of the substrates. Therefore, it is of great interest to develop high-efficiency and precision repairing technologies that will extend the lifetime of components. Laser cladding is one of the precision repairing method which overcome drawbacks of conventional repairing method. So first laser cladding is discussed and then how it can be used as repairing tool is discussed.

Laser cladding is a novel powerful tool for the repairing of metal components. Laser cladding is a relatively new process which is being used in industrial sectors like petrochemical, aerospace, machine and dies building, automotive, energy production to repair damaged high-value machine components like turbine blades, shafts, motors and to improve the corrosion and/or wear resistance of metallic components like tooling, pumps, valves, off-shore pipes.

The novel versatile laser cladding technology is such a repairing technology, which integrates laser technology, CAD/CAM technology, advanced materials processing technology and photoelectric measuring and control technology. Different similar techniques, for example direct light fabrication (DLF) [1], laser engineered net shaping (LENS) and direct metal deposition [2] have been developed and studied by many research groups in recent years. Laser cladding combines the two technologies of rapid prototyping manufacturing and laser cladding surface modification, and can be used to fabricate three-dimensional fully dense metal components directly from the CAD model.

Historically, fusion welding has been used for repair of surface cracks. One of the first methods is tungsten inert gas (TIG) welding [3]. However, while relatively easy to apply, this method produces a lot of heat and can cause high residual stresses, resulting in distortion and heat-related effects in the base metal [4]. Plasma transferred arc (PTA) welding [5] and electron beam (EB) welding [6] are alternative processes requiring lower heat input but needing more complex and expensive apparatus. EB welding, in particular, gives a very precise heat flux, but it needs a vacuum environment so is more expensive and difficult to apply to larger parts [7]. The high-velocity oxyfuel (HVOF) thermal spraying technique [8] is a procedure that has found use in many industries. There is less component distortion than with TIG welding and it has many advantages over plasma spraying, including deposition of a thicker and lower-porosity coating. However, tight control of depth and spread of deposited material is not possible, meaning an extensive secondary machining stage is usually required.

The process of laser direct metal deposition [9] is well suited to surface repair applications. LDMD involves creating a moving melt pool on a metal surface using a laser and blowing metal powder of the same or a different type into it using an inert gas stream. The added material increases the size of the pool, which rapidly solidifies into a raised track when the laser moves on. The deposition area can thus be precisely controlled. Residual stresses are formed but are lower than from TIG welding and can be compressive at the surface [10]. The physical and corrosion properties of the final material can be difficult to predict because it undergoes a repeated heating–cooling cycle [11], but they can in many cases exceed those of the parent material.

II. Experimental Procedures

The substrate was Nimonic alloy 263 with a sample size of 20mm x 60mm x 15mm whose constituents and their percentages were as follows:

Table 1. Chemical Composition of Nimonic Alloy 263

Component	**C**	**Al**	**Ti**	**Mo**	**Co**	**Cr**	**Fe**	**Ni**
Weight %	0.04-0.08	0.6	1.9-2.4	5.6-6.1	19-21	19-21	0.7	balance

Table 2. Physical Properties of Nimonic Alloy 263

Materials	Density (g/cm^3)	Melting point (^0C)	Specific Heat ($J/kg-^0C$)	Hardness
Nimonic Alloy 263	8.36	1355	461	HV 340

The physical properties of the powder material which was used to deposit a layer over substrate material was as follows:

Table 3 Powder Materials Properties

Name of Powder Material	Mesh size	Density (g/cc)	Melting Point Temp. (^oC)
Ni	325	8.908	1455
Cr	150-200	7.190	1907
Co	300	8.900	1495

The powder materials are mixed in the following composition:Ni-60% (by weight), Cr-20% (by weight) and Co-20% (by weight). 4% PVA was used for sticking purpose. PVA gives excellent sticking strength up to 250^o C temperature.

A 200 micron thick powder layer was applied on the substrate surface. Then the substrate was kept in furnace for $150\text{-}200^0$C for 20 min to dry it.

The experimental setup comprises of a Laser Source (2 kW Fiber laser machine with NC control laser head) and a coaxial inert gas supply nozzle with side inert gas supply attachment. A 2 kW fiber laser based on Ytterbium operating at 1085nm wave length has been used. This beam quality was 10 times better than a standard Nd-YAG laser. This laser was being used for the experiments. The laser head can be controlled by main control unit.

Fig. 2.Experimental set up

The prepared sample was laser cladded and laser power, gas pressure and laser scanning speed were set as the process parameters. Different values of these parameters, which were taken, are given below.

Laser power..........................1000 W, 1500 W
Gas pressure...........................1 bar, 1.5 bar
Laser scanning speed............1500,1600,1800,2000,2500,3000,3500 mm/min

Total 16 laser tracks were formed by laser cladding by different combinations of parameters which are summarized as follows:

Table 4: Experiments to optimize process parameters Powders: Ni+Cr+Co (60%+20%+20%) **Layer thickness-**200 micron **Sticking Agent**: 4%PVA; **Beam inclination angle** = 12^o;

Sample no. with track direction	Sample track no.	P_l (W)	v_s (mm/min)	Observations	Remarks
← Ni101 (200μm)	1.	1000	3500	Powder blown away	Y=6.0,Pr=1 bar,Z=-290
	2.	1500	3000	Partially deposited	
	3.	2000	2500	Do	
	4.	2000	2000	Fully deposited	
	5.	2000	1800		
	6.	2000	1600		
	7.	2000	1500		
	8.	2000	2000	3 overlap	Y=2.5, Pr=1bar,Z=-290
	9.	2000	1800	3 overlap	
	10.	2000	1600	3 overlap	
	11.	2000	2000	Fully deposited	Y=6.0,Pr=1 bar,Z=-280
	12.	2000	1800		

	13.	2000	1600		
	14.	2000	1600		Z=-280, Gas Pr=1.5bar
	15.	2000	1800		
	16.	2000	2000		

The powder layer was fully deposited under the following set of parameter:
Laser power............................1500 W
Gas pressure............................1 bar
Laser scanning aped................1600, 1800, 2000 mm/min

While with the other set of process parameters either the powder was blown away or the layer was partially deposited.

So total three set of parameters were found to be good for which three overlapping tracks were made for each set of parameter. These tracks were given name as track no.8 (scanning speed 2000 mm/min), track no. 9 (scanning speed 1800 mm/min), and track no. 10 (scanning speed 1600 mm/min), which are shown in table 6 above. All the characterisations were carried out on these three samples.

Following the laser cladding, the samples where good clad tracks are obtained are cut by wire EDM, polished in grinder polisher machine by using 140 mesh → 600 mesh → 1000 mesh, SiC emery paper → diamond paste of 0.25 micron. After polishing the sample was etched with the following reagent:

20 ml HCl(Conc.)+10 ml HNO_3(Conc.)+20 ml Glycerol+10 ml H_2O_2

The above reagent was used for revealing of microstructure for Ni-Co-Cr alloys [25].

III. Result and Discussion

Micro-hardness test:

Micro-hardness values for sample no.8(scanning speed 2000 mm/min), sample no.9(scanning speed 1800 mm/min) and sample no.10(scanning speed 1600 mm/min) has been measured along the transverse cross section of the deposited layer by Vickers micro hardness testing machine. At a particular distance from top surface of the coating two readings were taken and the average of those two is used for plotting graph.

Microhardness graph in figure 3 shows that the hardness of deposited layer increases from top of the deposited layer to the substrate whose microhardness was 342 HV0.05. Microhardness value of the substrate has been measured at five different points and average of all five reading has been coming out to be 342 $HV_{0.05.}$ Since the Titanium has not mixed in the deposited layer but due to alloying some titanium has come to the deposited layer from substrate and the percentage of titanium is increasing from top of the deposited layer to the substrate which may be the reason for increasing of microhardness from top of deposited layer to substrate.

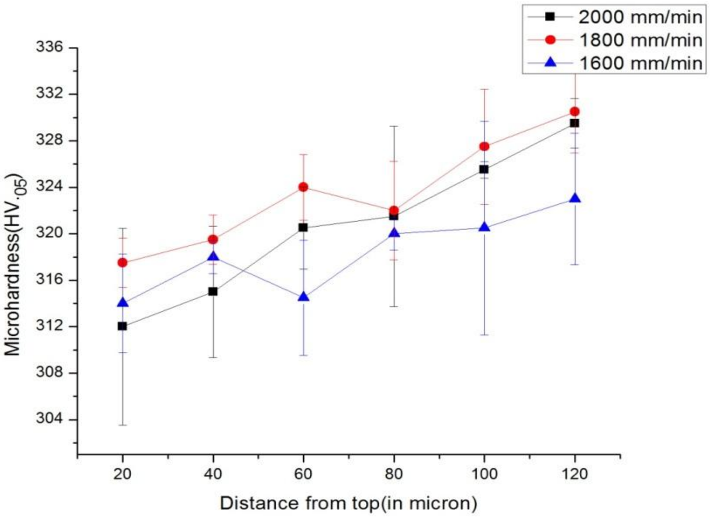

Fig. 3: Micro-hardness value of three samples measured along transverse section at different scanning speed of 2000, 1800 and 1600 mm/min.

Average Micro-hardness values for sample no.8(scanning speed 2000 mm/min), sample no.9(scanning speed 1800 mm/min) and sample no.10(scanning speed 1600 mm/min) is shown in figure 4. As it can be seen that average micro hardness for scanning speed 1800mm/min is little higher than the other two scanning speed but for all three scanning speed micro hardness is little lower than average micro hardness of substrate. It may be because of less percentage of titanium in the deposited layer.

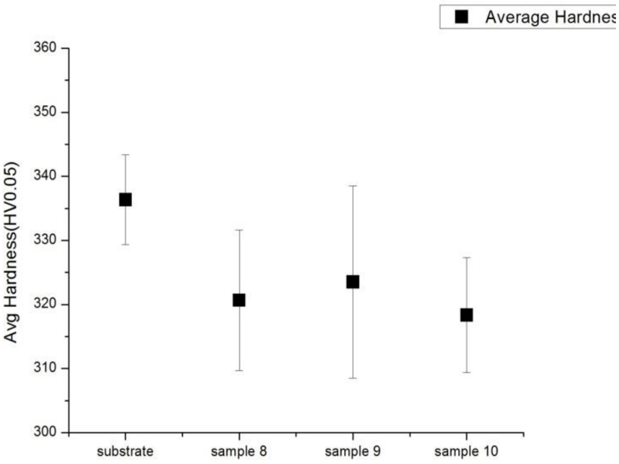

Fig. 4: Average micro hardness of sample 8, sample 9 and sample 10 with scanning speed of 2000mm/min, 1800mm/min and 1600mm/min

Microstructure:

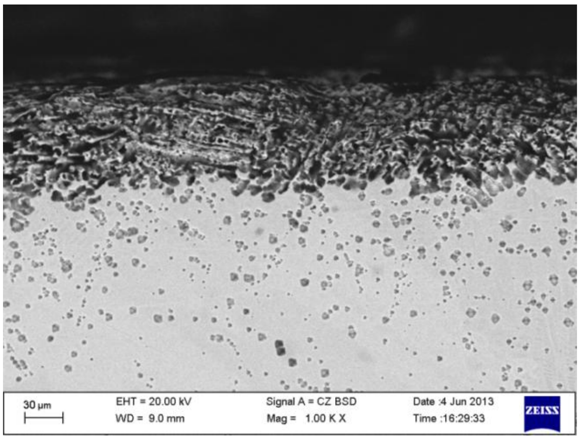

Fig. 5: SEM image for scanning speed 2000 mm/min

Figure 5 shows the SEM image for sample no. 8 (scanning speed 2000 mm/min).From the figure it can be seen that the thickness of deposited layer is around hundred micron though the powder layer thickness before laser cladding has been taken as two hundred micron. So it indicates that some powder has blown away.

Wear Test:

For the wear tests, 5 mm WC-Co balls have been used and the tests have been performed at 300 rpm under loads of 1 kg for 4 mm ball track diameter. The test was done for 30 minutes and in this time the distance moved by the ball on the track was calculated as 150 meters. Coefficient of friction was plotted with time for all the three samples and for substrate which is shown in the figures 6 below.

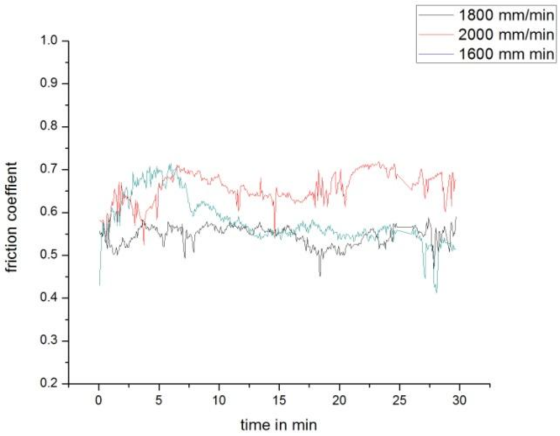

Fig. 6 : Coeffient of friction vs Time curve

For every sample specific wear rate has been calculated as follow:

Specific Wear rate = Wear volume / (Applied load x sliding distance) Wear volume was calculated from weight of the material which was removed from sample during wear test. Weight of the sample was calculated before and after wear test and difference between these two was the weight of the material which was removed from sample in the form of wear debris.

From the figure 6 it can be seen that among the three sample, sample no. 9 with scanning speed 1800mm/min has lowest coefficient of friction.The avg. Coefficient of friction are 0.56, 0.54, and 0.64 for scanning speed 2000mm/min, 1800mm/min and 1600 mm/min respectively while for substrate it was 0.58. Compared to substrate, sample no. 10 was showing poor tribological characteristic while for the other two samples the tribological performance was satisfactory.

Specific wear rate was least for sample no. 9 with scanning speed of 1800 mm/min and for all three samples specific wear rate was less than substrate material.

Table 5: Comparison of Specific wear rate

Sample name	**Specific wear rate (mm^3/N-m)**
Substrate	2.05E-04
Nimonic 8	1.79E-04
Nimonic 9	1.31E-04
Nimonic 10	1.56E-04

IV. Conclusion

A 200 micron layer of Ni-Co-Cr powder was successfully deposited on Nimonic alloy 263 by a 2kW fiber laser using preplaced powder method. The following conclusion can be derived from the experimental work.

- The thickness of the deposited layer was hundred microns while the powder layer thickness before coating was two hundred micron.
- The microhardness of deposited layer was slightly lower than substrate..
- Coefficient of friction was higher for substrate material than other three sample. And among the three sample, sample no. 9 with scanning speed 1800mm/min has lowest coefficient of friction.
- The knowledge achieved in this study would help in taking decisions in setting the process parameters required for subsequent repair a Nimonic component through layered manufacturing.

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