EXPERIMENTAL INVESTIGATION OF LASER METAL DEPOSITION OF FUNCTONALLY GRADED COPPER AND STEEL

Vinay Kadekar, Sashikanth Prakash and Frank Liou
University Of Missouri – Rolla
Rolla, Mo 65401

Abstract

Laser metal deposition is an emerging technology for producing fully dense metallic parts. This process shows a promising future for the deposition of functionally graded steel - copper alloys. Good thermal conductivity of copper and a high wear resistance of steel can be achieved in dies and cores. However, to accomplish this, there are many issues to be resolved, such as the formation of an undesirable phase, solidification cracking, porosity at the interface and difference in thermal coefficient of expansion between steel and copper. The influences of process variables, such as laser power, laser scan speed, composition, powder flow rate, on the success of the process, should be studied.

Introduction

H-13 tool steel is a widely used material for the manufacturing of dies due to its high wear resistance, but the low thermal conductivity limits the melt cooling rate and subsequent mold cycle time. Properties such as high thermal and electrical conductivity of copper make it a suitable material for the die casting industry. Copper is currently being considered for the deposition on dies made out of steel to enhance the thermal conductivity [1]. One of the processes to achieve this would be laser welding of copper onto steel. However, copper has a low absorptivity of the laser light and hence a high reflectivity. These properties of copper makes it difficult for laser welding as most of the laser light is reflected and a small portion of the energy is absorbed. Also the difference in thermal coefficient between copper and steel creates a large thermal stress at the clad interface resulting in a failure.

Laser Metal Deposition (LMD) is a layered deposition process where the metal powder is focused on a substrate and a laser beam is used to melt the powder and deposit it. The advantage of this process is that, complex geometries can be constructed with high degrees of accuracy to achieve near net shape with a solid model of the part. Figure 1 shows a Laser Aided Material Processing system (LAMP) at the University Of Missouri-Rolla which consists of a 2.5 KW Nd: YAG Rofin Sinar laser (at TEM_{00}) integrated with a 5-Axis FADAL CNC. The coaxial dual powder feeder system feeds the powder through four tubes which are connected to the nozzle. The advantage of using a dual powder feeding system is that it is capable of delivering two types of powder for functionally graded material parts. The laser deposition system has been integrated with a 5- Axis CNC machine to ensure a high finish quality, as the excess material can be

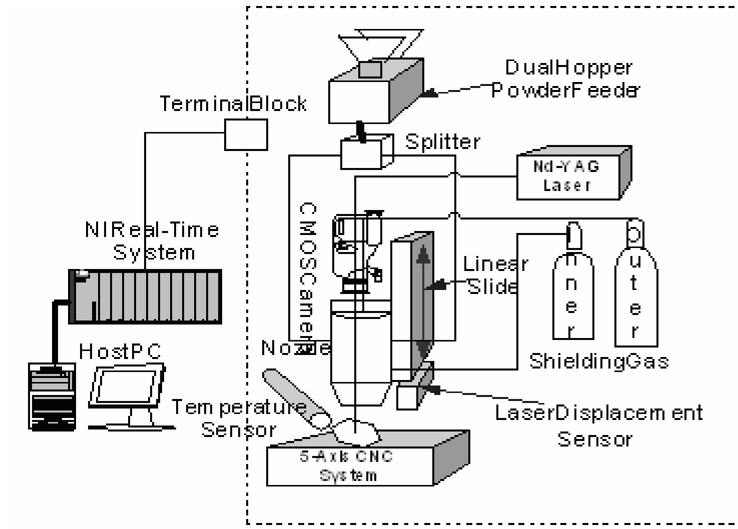

Figure 1. Laser Aided Material Processing System (LAMP).

machined. One more advantage of using the 5- Axis CNC machine is the capability to produce overhang parts. This avoids the use of support material thereby minimizing the build time and the time required for post processing.

There are a large range of layer thicknesses as well as deposition rates that can be achieved using laser deposition. The rate of deposition can be increased by increasing the laser power, powder flow rate and by decreasing the traverse speed. However, the requirement of a good part quality puts a limit on optimal deposition speeds. Both the layer thickness and the volume deposition rates are affected predominately by the specific energy and powder mass flow rate. Considering the factors, it has been reported that there is a positive linear relationship between the layer thickness and adjusted specific energy for each powder mass flow rate [2].

Design of Experiments

Experimental design is a critically important tool in the engineering world for improving the performance of a manufacturing process. The main advantage of this design is that an optimized result can be achieved in the least possible time. Hence, this tool can be implemented in designing a set of experiments for the deposition of copper on H13. The steps that should be used when designing such an experiment are given below.

1. Identifying the potential design factors that the experimenter may wish to vary during the experiment. A total of 7 factors with 2 levels were chosen in this process as shown in Table 1.
2. In selecting the response variable, the experimenter should be certain that this variable really provides useful information about the process. The response variables considered under study are porosity, cracks, micro hardness and thermal conductivity.
3. The number of experiments to be conducted depends on the number of factors and their levels. A total of 7 factors with 2 levels each would give rise to 128 experiments (2^7 experiments). Hence a 2^{7-3} fractional factorial design can be used

to reduce the number of experiments to 16 runs. Table 2 shows the experimental layout to run the 16 experiments with complete randomization.

4. Statistical methods should be used to analyze the data so that results and conclusions are objective rather than judgmental in nature.
5. Confirmation experiments should be done to validate the accuracy of the experiment.

Factors (unit)	**Levels**	
	-1	**+1**
1. Laser Power (W)	500	800
2. Feed rate (ipm)	20	40
3. Overlap (%)	25	35
4. Outer gas (psi)	8	12
5. Inner gas (psi)	3	5
6. Powder flowrate (g/m)	3	6
7. Standoff distance (in)	0.3	0.4

Table 1. Control Factor and their Levels.

RunOrder	Laser power	Feed rate	Overlap	Outer gas	Inner gas	Powder flowrate	Standoff distance
1	-1	1	-1	1	1	-1	1
2	1	-1	-1	1	1	1	-1
3	-1	1	-1	-1	1	1	-1
4	-1	1	1	-1	-1	-1	1
5	1	-1	1	-1	-1	1	-1
6	1	-1	1	1	-1	-1	1
7	-1	-1	-1	1	-1	1	1
8	-1	-1	-1	-1	-1	-1	-1
9	1	1	1	-1	1	-1	-1
10	-1	1	1	1	-1	1	-1
11	1	-1	-1	-1	1	-1	1
12	-1	-1	1	1	1	-1	-1
13	1	1	1	1	1	1	1
14	1	1	-1	1	-1	-1	-1
15	-1	-1	1	-1	1	1	1
16	1	1	-1	-1	-1	1	1

Table 2. Completely randomized experimental layout.

Discussion

The basic chemical composition of H13 is shown in Table 3. H13 is a chromium-molybdenum hot working steel, which can be used in either hot or cold working conditions. It has a high resistance to thermal fatigue, high toughness and low thermal conductivity when used conventionally. On the other hand copper has almost 13 times higher thermal conductivity than H13. This high thermal conductivity of copper is potentially significant in increasing the heat conduction in H13 dies. However, copper is typically considered as a contamination is steel. Figure 2 shows an iron copper system with a high solidification temperature range coupled with low solid solubility which

Element	C	Cr	V	Mo	Si	Mn	Ni	Fe
Composition (wt %)	0.4	5.2	1.0	1.5	1.0	0.4	0.3	bal

Table 3. Composition of H13 Tool Steel

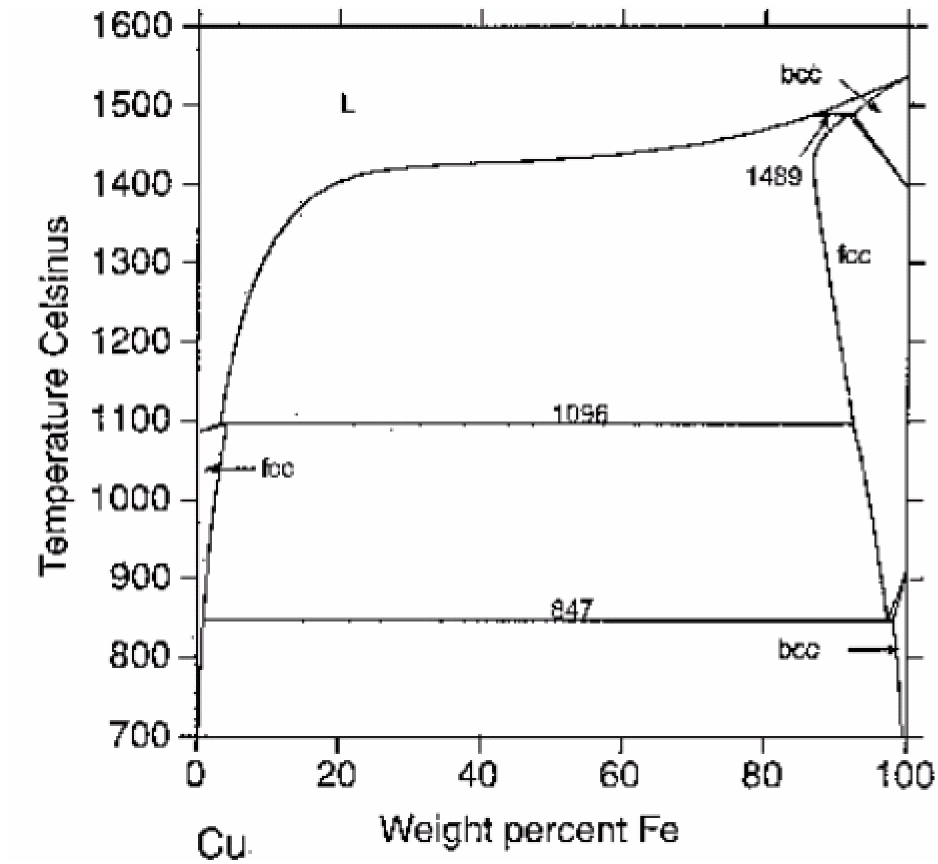

Figure 2. Cu – Fe phase diagram.

results in solidification cracking. This resultant cracking is a strong function of copper concentration in the deposit. Cracking is seen extensively when the percentage of copper is between 10-50 wt%, while deposits with copper concentrations below 5 wt% and above 55 wt% show a relatively low cracking [3,4]. At the intermediate copper concentration, say up to 55 wt%, copper wets in between the dendrites which thereby decrease the ability to withstand solidification stresses, resulting in the formation of cracks [5]. One way of reducing the cracking is to introduce an intermediate Nickel layer between the copper and steel deposit. Nickel is easily soluble in copper and steel, thereby making it a good choice for intermediate layer. The other important factor to be examined is the porosity. This may result due to the copper powder's dendrite morphology. Further research has to be conducted to closely examine the cracks and the porosity. This can be done by conducting iterative experiments to hone in on the best possible level values of the control parameters that are least sensitive to the variations and are more repeatable.

References

1. F.F Noecker II and J.N. DuPont, " Functionally Graded Copper-Steel Using LENS Process", Rapid Prototyping of Materials, Symposium Proceedings, Columbus, OH, United States, Oct. 7-10, 2002 (2002), 139-147
2. Mazumder J., Choi J., Nagarathnam K., Koch J., and Hetzner D., "The Direct Metal Deposition of H13 Tool Steel for 3-D Components", JOM, 49(5), 1997, pp. 55-60.
3. Vainerman, A.E., Osetnik, A.A. "The Formation of Cracks During the Deposition of Copper Alloys to Steel", Automatic Welding, Vol 21, June, 1968, pp 22-25.
4. Dixon, B. "Weld Metal Solidification Cracking in Ferritic Steel- A Review", Australian Welding Journal, Vol 26, summer, 1981, pp 23-30.
5. Rick Noecker "Cracking Susceptibility of Steel Copper Alloy", Advanced Material & Processes, Feb 2003.