Design of Embedded Resistance Heating Element using Rapid Manufacturing Process

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Abstract

This paper discusses the design of heating element suitable for embedding in a rapid manufacturing process. A specific pattern is built using the laser deposition Process available at the University of Missouri - Rolla. A resistance heating element which is then cast into place using a castable refractory material, which acts as an electrical insulator. An application of this technology is for preheating the substrate before direct metal deposition.

1 Introduction

Laser metal deposition typically induces significant thermal stresses on the deposited structures. These thermally induced stresses affect the final geometry of the part, which may cause the geometry to vary from what is required. This, in effect, reduces the robustness of the laser metal deposition process. Thermal stress is intensely dependent upon the high initial cooling rate of the melt pool and the variation in temperature over time as the process builds a part.

The part in laser deposition process is deposited layer by layer. Observing the change in heat at any particular point on the part, it is seen that reheating occurs at that point. Figure 1, below, demonstrates a possible heating and cooling cycle seen by any given point on a laser deposited structure.

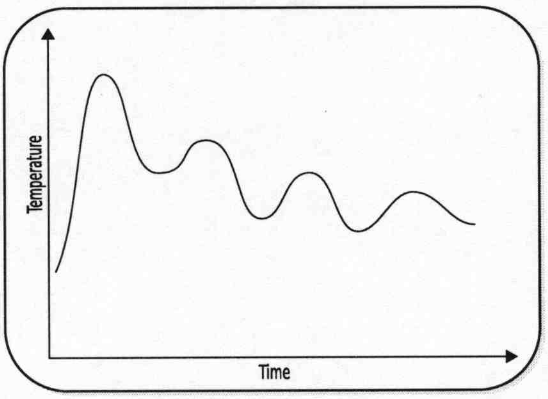

Figure 1: Cyclic heating and cooling typical of the laser deposition process.

In the process of laser aided deposition the 1st layer which is in contact with the substrate will be

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subjected to prolonged heating and the final top layer will have a very rapid cooling rate. This varies the micro structure through out the part.

The conditions in the laser deposition process can be compared to the traditional heat treatment process. Prior to deposition the substrate is at room temperature. The 1st layer of deposit undergoes immediate quenching upon solidification. High alloyed steel, such as H13 tool steel when heated above the austenitizing temperature partially dissolves the carbide and alters the matrix. The ferrite is transformed to austenite. If this steel is quenched rapidly in the hardening process, the carbon atoms do not have time to reposition themselves to allow the reforming of ferrite from austenite. Instead they are fixed in a position where they really do not have enough room. The result is high microstresses that can be detected as increased hardness. This hard structure is called martensite. When H13 tool steel is hardened the matrix is not completely converted into martensite. Some austenite is always left, known as "retained austenite". Hence, after cooling, the steel has a microstructure consisting of martensite, carbides, and retained austenite. This structure has high inherent stresses. This can cause cracking. Preheating the substrate avoids immediate quenching of the laser deposit. H13 tool steel deposit can be gradually cooled down if the substrate is preheated. This avoids the high inherent stresses in the deposited part.

In the traditional heat treatment process material should be tempered immediately after quenching. It is also to be made sure that quenching should be stopped at a temperature of 50-70°C and tempering should be done at once.

Laser deposition is a layer by layer process. The 1st layer deposited on the substrate is subjected high cooling (quenching). Next layer is deposited and the 1st layer is reheated. This is an analogy to the traditional heat treatment process. As mentioned above, to obtain hardness, toughness and dimensional quality, the quenching should be stopped at particular temperature (usually 50-70 °C) [1].

From the above few studies it is seen that preheating the substrate is necessary to obtain good quality parts without cracks.

2 Preheating of Substrates

Laser welding of tool steel - The main problem in welding tool steel is its high hardenability. Weld cools quickly once the heat source is removed and the weld metal and part of the heat affected zone will harden. This transformation causes stresses with concomitant risk of cracking. Due to this fact tool steel cannot be welded at room temperature without considerable risk of cracking. Hence preheating becomes a necessary criterion for laser welding [2].

Laser Deposition - Laser deposition is very much similar to laser welding process. As mentioned in the introduction, laser deposition process is an analogy to traditional heat treatment process and in order to obtain good quality parts it is necessary to maintain a particular temperature during quenching. This is where preheating becomes a necessity.

Machining - The main factor that affects machining is the chatter. The amount of chatter during machining will very much be reduced when the part is preheated [3]. So this makes machining easy and further more high surface finish can be achieved. This is another application of the preheating the substrate.

2.1 Advantages of Preheating

- Reduce the risk of hydrogen cracking: Cracking is caused due to the diffusion of hydrogen to the highly stressed parts of the deposition.
- Reduce the hardness of the weld heat affected zone
- Reduce shrinkage stresses during cooling and improve the distribution of residual stresses.
- Reduces the chatter during machining [3]

Residual stresses can be inhibited to a great extend by preheating. This in turn prevents hydrogen cracking. Hence from the above mentioned reviews it is found that preheating the substrate is a necessity for not only laser deposition process but also laser welding process too.

3 The Preheating element

The previous sections elaborate the need for a preheating element to preheat the substrate and in this section the procedure followed to design and fabricate the preheating element is briefly explained.

The basic idea of the preheating element is to manufacture a substrate with an embedded resistance heating element it. This substrate will then be used as the base to deposit parts. The method of fabrication of this preheating element is mentioned in the following paragraphs.

The process used for the fabrication of the preheating element is the laser aided manufacturing process (LAMP), developed at the University of Missouri - Rolla [5–13]. It is done with the help of a 3016L Fadal CNC machine which is integrated with a 1 KW diode laser with a flat power distribution. The Fadal 5 axis CNC machine used in LAMP lab consists of an X,Y table, a movable Z axis and an A and B rotary axis.

A heating element is fabricated via the following procedure:

1. A 4x4 inch substrate which is of tool steel is fixed on the vice.
2. H13 tool steel powder is to be deposited on this substrate.
3. A 2x3 inch pattern as required is deposited on the substrate.

The deposit pattern is shown below. As shown figure 2 the channels in between the deposit is for the placement of a resistance heating element which heats up the substrate on connecting it to a power supply.

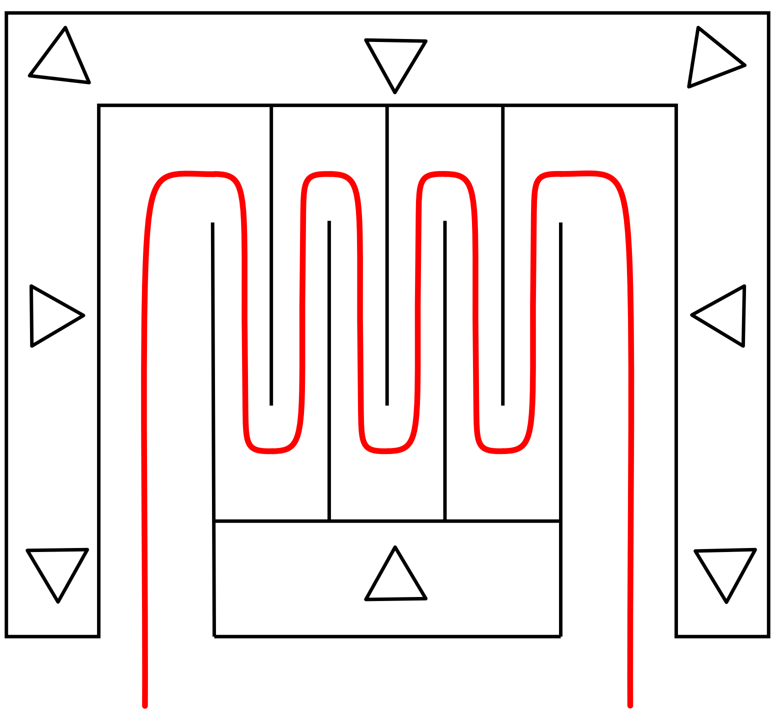

Figure 2: Heating element deposition path. The red line indicates the intended position of the Ni-Cr element.

At first the pattern is deposited using direct metal deposition process. A resistance heating element, which in this case is Ni-Cr wire is cast in the pattern using a castable refractory material, Ceram Cast.

After casting, the top portion is attached via laser welding. In order to make sure that the welding takes place correctly, the complete deposition, machining and welding processes should be done one after the other without removing the substrate from the vice.

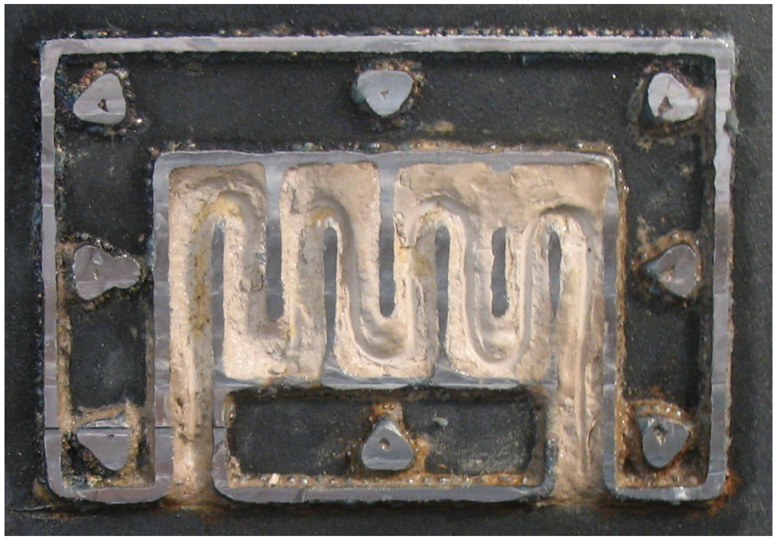

Figure 3: Heating element structure with castable refractory material added.

Conduction of heat should take place through the top welded plate and not through the side. If the heat is dissipated through the sides then efficient heating will not take place and this will not ensure the proper use of the preheating element.

In the design of the Heating element the primary importance is the conduction of heat. Heat should be conducted through the top welded portion. In order to achieve this, the channel was separated from the outer wall by air gap Figure 4. This would ensure less amount of conduction of heat through the sides.

Unfortunately the air gap does not provide any support to the top weld plate during machining. In order to overcome this issue triangular structural supports are deposited in between the air gaps. This provides sufficient support to the weld plate during machinng.

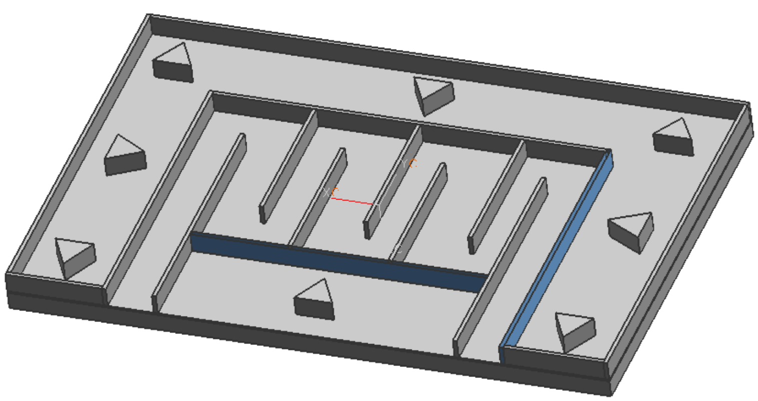

Figure 4: CAD representation of the deposited heating element structure.

The pattern is deposited and the resistance heating element is cast in the pattern using ceram cast. Ceram cast provides electrical insulation. The resistance heating element is connected to a DC power supply.

4 Future Work

- Fabrication of the heating element using laser aided manufacturing process
- Testing the Microstructural effect.
- Comparison of the Microstructure with and without the use of preheating element.
- Provide a constant temperature during deposition process to change the microstructure.

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