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## Comparison of Thermal Properties of Laser Deposition and Traditional Welding Process via Thermal Diffusivity Measurement

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### Abstract

Laser deposition is an effective process for mold and die repair. In order to improve the part repair quality, the process impact on thermal diffusivity and thermal conductivity needs to be understood for laser deposited, welded and virgin H13. In this paper, H13 tool steel samples were made by laser deposition, welding and virgin H13 and then cut into pieces. Experiments were conducted to investigate the thermal diffusivity and conductivity. A laser flash method is used to test these samples. The future work and opportunities are also summarized.

**Keywords:** Laser Flash, laser deposition, tool steel, H13

### Introduction

Nowadays, part repair technology is gaining more interest from military and industries due to the benefit of cost reducing as well as time and energy saving. Traditionally, part repair is done in the repair department using welding process. The limitations of the traditional welding process are becoming more and more noticeable when accuracy and reliability are required<sup>1</sup>. In addition, the life of the mold and die parts after being repaired by welding process is much shorter than that of the virgin metal according to industrial experience. In LAMP (Laser Aid Manufacturing Process) lab, the laser deposition process is developed to repair the parts (Figure 1), for example the worn die shown.



Figure 1. The die after repair by laser deposition and machined by CNC

Thermal conductivity and thermal diffusivity play an important role in the life of molds and dies. Higher thermal diffusivity means that thermal equilibrium will be reached faster when the temperature changes. A good thermal diffuser will react more quickly to environmental

temperature changes. Higher thermal conductivity equates to the transfer of more thermal energy per unit of time under steady state conditions <sup>2</sup>. In this paper, different samples of tool steel made by virgin, welding and laser deposition were prepared and the thermal properties of these samples were investigated by the laser flash method.

### 1. Theory of Experiment.

Laser flash method was first introduced by Parker, Jenkins etc in 1960<sup>1</sup>. The front surface of a sample is heated instantaneously and heat conducts through the sample. The back surface temperature T vs. time t has this relationship:

$$T(L,t) = \frac{Q}{\rho CL} \left[ 1 + 2 \sum_{n=1}^{\infty} (-1)^n \exp\left(\frac{-n^2 \pi^2}{L^2} \alpha t\right) \right] \quad (1)^3$$

where Q is the radiant energy incident on the front surface at t=0,  $\rho$  is density, C is specific heat and  $\alpha$  is thermal diffusivity, L is the thickness of the sample.

Two dimensionless parameters, V and  $\omega$  can be defined:

$$V(L,t) = T(L,t) / T_M \quad (2)^3$$

$$\omega = \pi^2 \alpha t / L^2 \quad (3)^3$$

$T_M$  represents the maximum temperature of back surface. The combination of 1, 2 and 5 yields:

$$V = 1 + 2 \sum_{n=1}^{\infty} (-1)^n \exp(-n^2 \omega) \quad (4)^3$$

Equation (4) is plotted in Fig. 2:

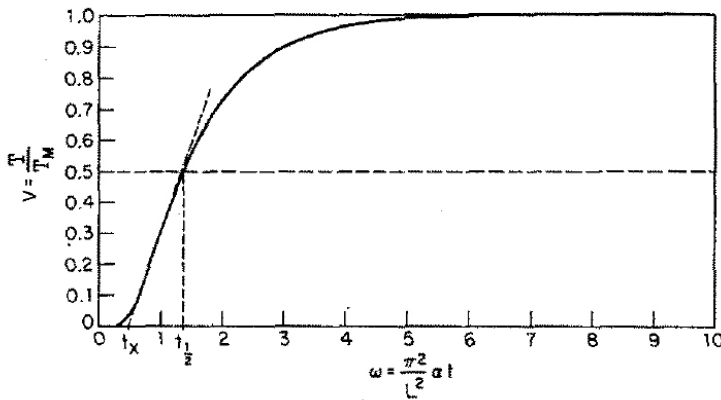


Fig. 2. Dimensionless plot of back surface temperature history <sup>3</sup>

One way of determining  $\alpha$  has been deduced from Eq (4) and Fig.2. When V is equal to 0.5,  $\omega$  is equal to 1.38, so

$$\alpha = \frac{0.1388}{t_{1/2}} L^2 \quad (5)^3$$

Where  $t_{1/2}$  is the time required for the back surface to reach half of the maximum temperature rise.

Thermal conductivity  $\lambda$  is calculated using the value of thermal diffusivity and specific heat.

$$\lambda = \alpha \cdot C_p \cdot \rho \quad (6)^3$$

( $\alpha$  : Thermal diffusivity,  $\rho$  : Density,  $C_p$ : Specific heat, is determined by this laser pulse and almost equal to the energy of the laser)

## 2. Experiment setup:

The purpose of the experiment is to test  $t_{1/2}$  - the time required for the back surface to rise to half of the maximum temperature it can reach according to equation (5). The front face of a small disk-shaped sample was subjected to a very short burst of radiant energy. The source of the radiant energy is a laser irradiation. The resulting temperature rise of the rear surface of the sample is measured and recorded by the real time system.

Figure.3 shows the experiment design. The experiment system contains laser, real-time system and temperature sensor. The laser pulse and data record are both controlled by real-time system. The laser was a 50 watt Diode laser with very short pulse at about 5ms. The temperature sensor is RTD (Resistance Temperature Detector) (Figure 4), in order to achieve good heat conduction from sample to the sensor, thermal grease was applied in between the sensor and samples. A thermal couple was used before as the temperature sensor. However RTD is more accurate and has been developed to be so small that it fit for very tiny sample. The infrared (IR) sensor is also applied in many systems for recording the temperature rise curve<sup>4</sup>. It can measure thermal properties at very high temperature. We chose RTD over an IR sensor for the reason that it is simpler and effective.

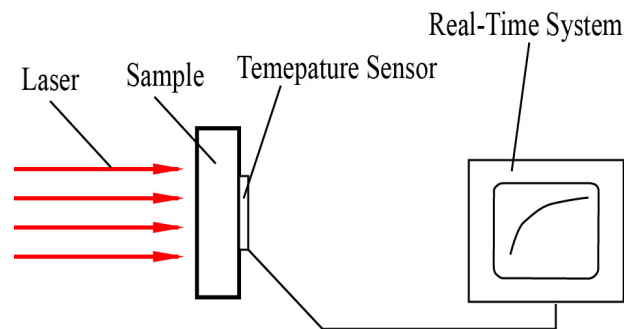


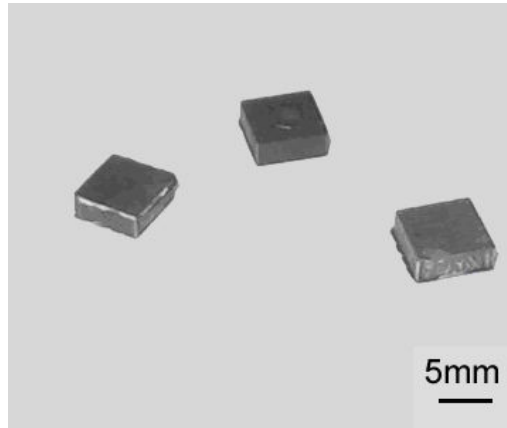
Figure 3. Laser Flash Method Experiment Design

The hardware and software of the Real-time System come from National Instrument and the program was based on the Lab-view 8. The real-time system can achieve two functions: control

laser to create laser pulse in desired duration, measure and record the back face temperature of samples through the RTD sensor.

### 3. Sample preparation:

Laser deposition cladding, welding cladding and virgin tool steel samples, which are all tool steel H13, were cut into small pieces with the size of 5mmX5mmX2mm. The thickness of the samples was important for the test.



*Figure 4- Specimens*

### 4. Experiment:

The sample was placed on the RTD sensor and the laser nozzle was aligned. The real-time system controls the laser to flash on the front side of the sample and record the rise curve of the back side temperature of the sample simultaneously. A typical temperature rise curve is shown in Figure-5. The value of  $t_{1/2}$  was measured as shown in Figure-5 and the thermal diffusivity and thermal conductivity was calculated according to equation 5 and 6. For virgin, welding and laser deposition tool steel samples, we assume all samples had the same density and specific heat:  $C_p=0.45 \text{ J/g-c}$ ,  $\rho=7.8 \times 10^3 \text{ kg/m}^3$ .

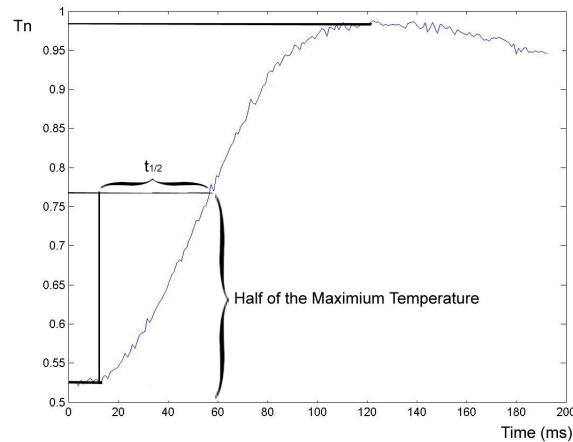


Figure 5- typical back-face temperature vs. time rise curve

## 5. Result:

Six specimens were prepared for the experiment, two for virgin metal, two for laser deposition and two for welding. Each sample had three replicates. The results are shown in table 1:

Table 1- Thermal Conductivity Experimental Results

	Sample No.	Dimension (mm)	Thickness (mm)	$t_{1/2}$ (s)	Average Thermal Diffusivity ( $\times 10^{-6} \text{m}^2/\text{s}$ )		Average Thermal conductivity (W/mK)	
Virgin part	#1	5.0X5.0	2.011	0.102	5.50	5.67	19.7	20.3
	#2	5.0X5.0	2.028	0.098	5.83		20.9	
Welding	#3	5.0X5.0	2.008	0.173	3.23	3.03	11.6	11.5
	#4	5.0X5.0	2.055	0.185	2.83		11.4	
Laser deposition	#5	5.0X5.0	2.039	0.167	3.67	3.77	13.1	13.5
	#6	5.0X5.0	2.012	0.145	3.87		13.9	

The virgin samples can be regarded as the reference samples, and the thermal conductivity of virgin samples is in the range it should be - around 20 W/mK. Both laser deposition and welding specimens have lower average thermal conductivity than virgin H13, welding drops about 43% and laser deposition drops about 1/3, but laser deposition has higher average thermal conductivity than welding by 22%.

## 6. Analysis

There are many reasons why the different sample types have different thermal properties. Laser deposition has small heat affected zone than conventional welding, so that laser deposition has more homogenous microstructure, it is one of the reasons why welding samples have lower

thermal diffusivity and conductivity than laser deposition samples.

## **7. Conclusion:**

In this paper, the laser flash method to measure thermal diffusivity was introduced. The experiment system based on the laser flash method was designed and conducted. The results show that repaired H13 tool steel parts have lower thermal diffusivity and conductivity than virgin metal and the parts repaired by laser deposition have higher thermal diffusivity and conductivity than those repaired by traditional welding. It means that laser deposition process will be better for part repair considering the thermal diffusivity and thermal conductivity than traditional welding process.

The next step is to study the microstructure and compare the difference between laser deposition, welding and virgin tool steel H13. Also the samples are tested at the room temperature. Thermal properties of the samples at higher temperature should be investigated and a furnace will be added on this system and to keep the samples at proper constant temperature.

## **8. Acknowledgement:**

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