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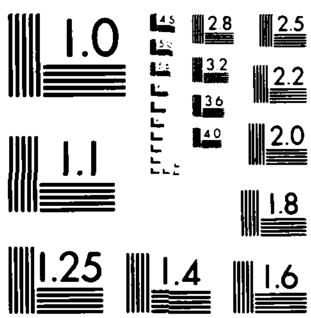

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STUDY OF THE COATINGS ON METAL SURFACE FOR LASER TREATMENT

by

Su Baorong, Wang Zeen, et al

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STUDY OF THE COATINGS ON METAL SURFACE FOR LASER TREATMENT

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ABSTRACT

A method to measure the absorptivity of powder coatings on metal surfaces is presented. The absorption characteristics of eight kinds of powder layers coated on common metals have been investigated using CO_2 laser beam with low and high power density.

I. INTRODUCTION

The effect of metal surface condition on the absorptivity of a laser beam will influence the effectiveness of laser treatment directly because most metals are good conductors and the polished metal surfaces have very high reflectifity with respect to 10.6 micron light. These facts imply some technical difficulties to laser treatment. Therefore, when we use this laser beam as a heat source, we must understand the absorption characteristics of the treated metal surface with respect to the laser in order to determine the needed power density, moving speed, and coating type.

In the past, most of the studies were carried out on high vacuum polished metallic materials at room temperature [1]. As a matter of fact, the metal surface is not under these conditions during laser heat treatment. Actually, the absorptivity which corresponds to the various surface conditions will vary with the laser power density and moving speed.

* Manuscript received on October 5, 1981.

Huang Tian Ji Ming published experimental results on the absorption characteristics of aluminum and stainless steel in 1971 [2]. He believed that the absorptivity of a powder coated metal surface had to be obtained using heat conduction theories [3]. However, for a multiple mode diffuse focus light beam, it is not possible to be treated as a point light source. Therefore, it is not suitable to use its absorptivity using the heat conduction theories. Nevertheless, the coating of the metal surface with powder is the most convenient and effective treatment method to increase the absorptivity. It is seriously considered by many people [4].

This paper presented a method to measure the absorptivity of powder coated metal surfaces. The emphasis was placed on the study of absorption characteristics of insulating and non-insulating powder coatings on metal surfaces under a CO_2 laser beam at low and high power densities.

II. EXPERIMENTAL METHODS

1. Determination of the Absorptivity at Low Power Density CO_2 Laser Beam: Eight experimental materials were chosen, viz carbon steels (No. 20, No. 45, T10), alloy steel (20Cr, GCr15, 33CrNiMoA) stainless steel, and aluminum alloys. The sample size was 12x12x4 mm. The sample surface was first polished or machined roughly using a milling machine. Then, they were coated with zironium oxide, titanian oxide, manganese phosphate, carbon black, graphite, nickel boron silicon alloy powder, and the oxidation darkening treatment of aluminum. The sample was placed in the calorimeter shown in Figure 1. A CO_2 waveguide laser was used as the light source (power density was 14.6 watt/cm^2) and the illumination time was 3 minutes. A multiple reflection sensitive detector is used to measure the reflected and scattered signals upon illumination. Simultaneously, a JG-3-S type digital laser pwoer monitor was used to monitor the

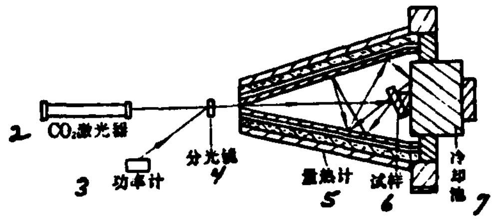


Figure 1. The absorptivity measuring device.

2- CO_2 laser; 3- Power meter; 4- Beam splitter; 5- Colorimeter; 6- Sample; 7- Cooling reservoir

stability of the laser power output. The measured numbers, after the correction using the known reflectivity of a gold plated film (98.6%), can express the absorptivities of various surface conditions.

2. Determination of Absorptivity at High Power Density: The experimental materials chosen were No. 20, No. 45, T10, CGr15, and 33CrNiMoA. The sample size was 28 x 20 x 17 mm. The surfaces were coated with zirconium oxide, manganese phosphate, carbon black, graphite and nickel-boron-silicon alloy powder, respectively. The grain size of the powder was under 200 mesh. A one-thousand watt transverse CO_2 lawer was used as the heat source to conduct laser heating at various power densities and moving speed. Then, a metallographic microscope was used to measure the transverse cross-sectional area of the heat treated area.

Absorptivity

$$R_0 = \frac{A_0}{A} \tag{1}$$

A_0 is the transverse cross-sectional area of the laser heat treated area with reflective loss; A is the transverse cross-sectional area at which the laser beam is completely absorbed by the metal surface.

When the parameters of the metallic materials and those of the laser technique are identical, then:

$$\frac{R_0}{R_1} = \frac{A_0}{A_1} \qquad (2)$$

A_1 is the heated area of another type of surface coating; R_1 is the absorptivity of another type of surface coating.

In view of the fact that the laser heat treatment area of the zirconium oxide coating gradually increases with increasing power density before melting, we chose to take the low power density absorptivity of the zirconium oxide coating as approximately equal to 1800 ~ 2000 watt/cm^2. Hence, it was possible to place the absorptivity measured using the experimental method 1 into Equation (2) in order to obtain the absorptivities corresponding to various power densities and moving speeds.

III. RESULTS AND DISCUSSION

1. The absorptivities at low CO_2 laser power density have been measured under various metal surface conditions using the apparatus shown in Figure 1 (see Table 1). The results indicate that the absorptivity of metal surface is closely related to factors such as coating characteristics, metal surface polish, and the composition of the substrate. The absorptivity of both very roughly treated and polished metal surfaces increases with the increasing carbon content in the steel. Under the same conditions, the absorptivity of high carbon steel treated surface is about twice as that of low carbon steel because the absorptivity R_0 is proportional to the square root of the resistivity η_0 of the metallic material, i.e., $R_0 = 112.2\sqrt{\eta_0}$ (2). Due to the fact that the carbon content of the high carbon tool steel T 10 is high, its resistivity is also high. Therefore, the absorptivity is also increased. Similarly, the absorptivity of a stainless steel treated surface is 4 times greater

than that of the 20Cr steel. The difference in absorptivity of these two materials does not change after polishing. After polishing for the treated surfaces of various materials listed in Table 1, the absorptivity decreases by 2-6 times. Hence, we can see the significant effect of surface polishing on absorptivity. In spite of a very coarse metal surface, the absorptivity with respect to CO_2 laser beam is still low. It is not possible to directly treat it with a low power laser. If corresponding powder is coated on the metal surface, then the effectiveness of laser treatment can be significantly improved. Experimental results showed that the absorptivity of any metal surfaces coated with an insulating coating is almost unrelated to the substrate material. It is determined by the coating characteristics. However, for a metal surface with a non-insulating coating, the absorptivity is related to the chemical composition of the substrate material. Due to the fact that part of the energy is quickly transmitted to the surface of the substrate after the coating is illuminated, if the electrical resistance of the substrate is high, its absorptivity is also high. Just as shown in Table 1, the absorptivities of No. 45 steel surfaces coated with carbon black, graphite, and nickel-boron-silicon coatings are higher than those of No. 20 steel.

2. The relations between absorptivity under high power density, heat treatment area, and laser treatment technical parameters. Figure 2 shows that, along with the high spot area increase to the laser, it further deviates away from the assumptions of the point light source theory. Therefore, it is not suitable to use the heat conduction theory to determine the metal surface absorptivity of a multiple mode light beam, especially for a diffuse focus light beam.

Figure 3 shows that the laser heat treatment transverse cross-sectional area increases with power density for the three materials coated with zirconium oxide on the surfaces. The melting of zirconium oxide with increasing power density was not serious. However, the heat treated area of the carbon black coating gradually

TABLE 1. THE ABSORPTIVITIES AT LOW POWER DENSITY

Material	Very course treated surface	Polished surface	Absorptivity (%)						
			Insulating Coating				Non-insulating coating		
			8	9	10	11	12	13	14
20*	23.3	4	90.1	89.3	88.9		67.3	54.9	73.8
45*	7.1* 100*砂纸 17	5.6	90.1		87.3		83.5	80.6	82.8
T10	45.3	19.4	92.1				83.3		
20Cr	16.7	6	89.2	89.3	88.3		78.9	54.8	86.9
15 不锈钢	68.4	23.5	89.6				83.8		
16 铝合金						81.9			

Key: 8- Zirconiun oxide; 9- Titanium oxide; 10- Manganese phosphate: 11-Aluminum oxide; 12-Carbon black; 13-Graphite; 14-Nickel-boron-silicon; 15-Stainless steel; 16-Alum. alloy; 17-polished by 100# sandpaper.

TABLE 2. THE CORRELATION BETWEEN THE ABSORPTIVITY OF NO. 45 STEEL COATING AND FACTORS SUCH AS COATING THICKNESS.

	涂 料 10	涂层厚度 (11)	功率密度 12	移动速度 13	表面硬度 14	硬化层宽 15	硬化层深 16	热作用面积 17	涂层吸收率 18
19	炭 黑	0.05	2000	14.7	838.5	5.6	0.45	1.68	60.5
20	炭 黑	0.1	2000	14.7	843.3	4.4	0.65	1.91	68.8
21	石 墨	0.05	3000	14.7	745	4.9	0.55	1.8	63.7
22	石 墨	1	14000	30	653.8	1.8	0.18	0.21	7.6
23	氧化锆	0.05	2000	14.7	889	5	0.75	2.5	90.1
24	氧化锆	0.2	2000	14.7	855.5	4.8	0.73	2.34	84.3

Key: 10- Coating material; 11-Coating thickness (mm); 12-Power density (watt/an^2; 13-Moving speed min/sec; 14-Surface hardness (Hv); 15-Width of the hardened layer (mm); 16-Depth of the hardened layer (mm); 17-Heat treated area (mm^2); 18-Coating absorptivity (%); 19-Carbon black; 20-Carbon black; 21-Graphite; 22-Graphite; 23-Ziconium oxide; 24-Zirconium oxide.

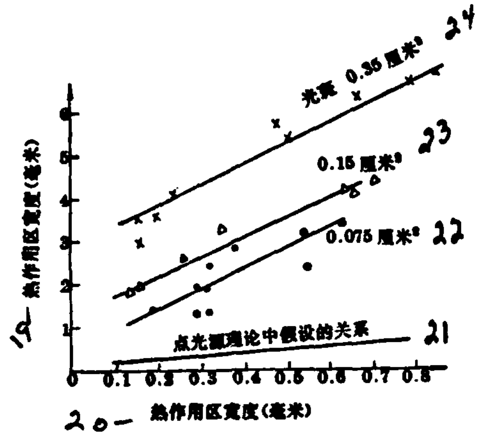


Figure 2. The relation between width and depth of No. 45 steel under laser heat treatment.

19- Width of the heat treated zone (mm);
20- Width of heat treated zone (mm);
21- The assumed relationship in the point light source theory; 22- 0.075 cm^2; 23- 0.15 cm^2;
24- Light spot 0.35 dm^2

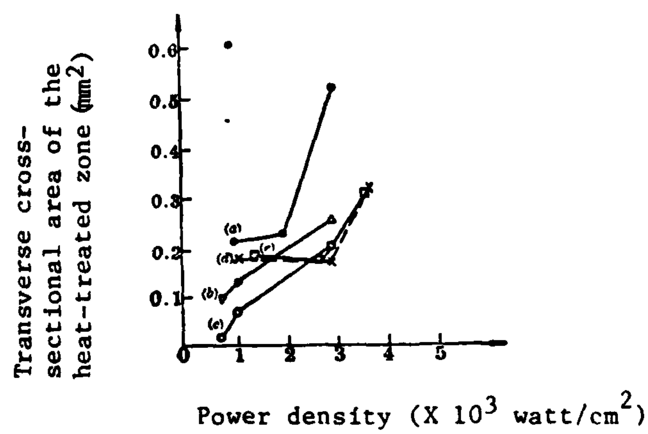


Figure 3. The relation between the transverse cross-sectional area of the heat treated zone and the power density.
(a) No. 45 steel coated with zirconium oxide;
(b) T10 coated with circonium oxide
(c) 33CrNiMoA coated with zirconium oxide.
(d) T10 coated with carbon black 14.7
(e) No. 45 steel coated with carbon black; laser moving.

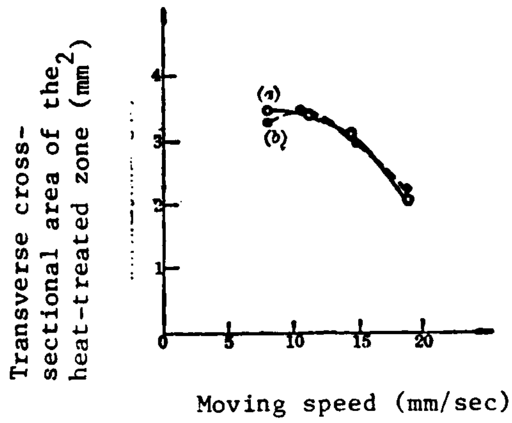


Figure 4. The relation between the heat treated area and the laser moving speed.

(a) T10 coated with carbon black.
(b) GCr15 coated with carbon black; power density: 4600 watt/cm2

decreased with increasing power density. When the power density reached a certain point, its cross-sectional area abruptly surged up. This indicated that the melting of carbon black with increasing power density became very serious and the abrupt surge of heat treated area indicated the melting of the metal surface.

Figure 4 shows that the heat treated area of the carbon black coating gradually increases with increasing laser movement speed. When the movement speed reached a certain value, the heat treated area decreased with increasing moving speed. Because of the slow moving speed, the carbon black was easily melted. However, when the movement speed is sufficiently fast, the total laser energy illustrated on the coating is also decreased.

Figures 5 and 6 show that the variations of absorptivity of the coating with power density and moving speed can be divided into three stages; When the power density is less than 1800 watt/cm^2 and the movement speed is less than 8 mm/sec, the variation of absorptivity is weak. At medium power densities, the absorptivity of the

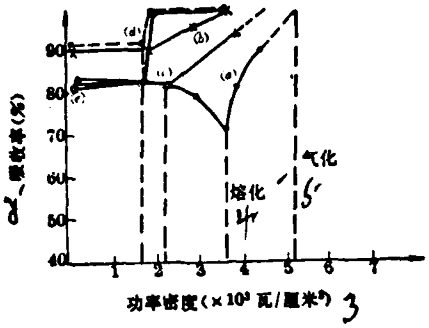


Figure 5. The relation between surface coating absorptivity and power density.

(a) T10 coated with carbon black;
(b) No. 45 steel coated with zirconium oxide;
(c) No. 45 steel coated with carbon black;
(d) T10 coated with circonium oxide
(e) 33 CrNiMoA coated with zirconium oxide;
Moving speed = 14.7 mm/sec.

2- Absorptivity (%); 3- Power density ($x10^3$ watt (cm^2); 4- Melting; 5- Vaporization;

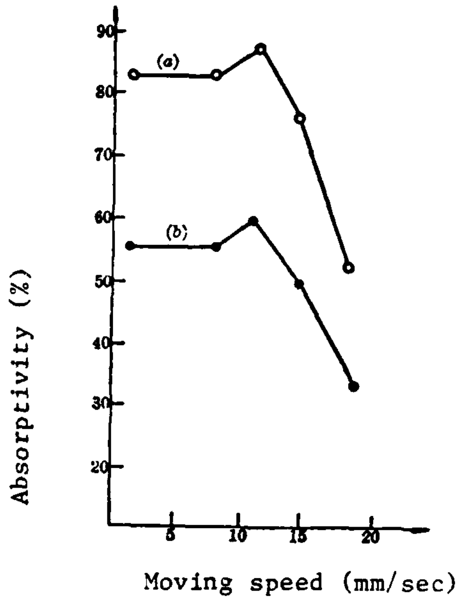
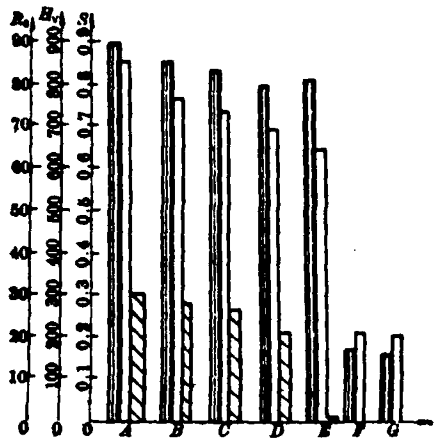
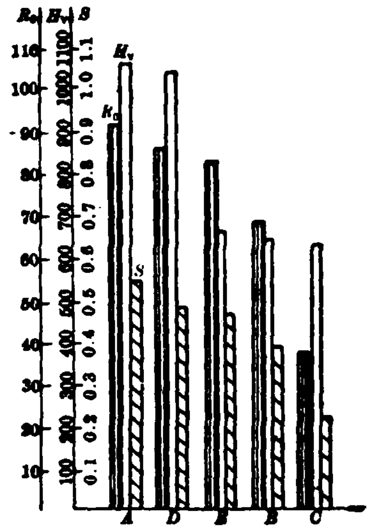


Figure 6. The correlation between surface coating absorptivity and laser light moving speed.

(a) T10 coated with carbon black;
(b) GCr15 coated with carbon black;
Power density = 4600 watt $/cm^2$.



(a) Power density; 2000 watt/cm^2,
Moving speed: 14.7 mm/sec



(b) Power density: 4000 watt/cm^2;
Moving speed: 14.7 mm/sec.

Figure 7. Comparison of absorption characteristics of various coatings for No. 45 steel.

A- Zirconium oxide; B- Manganese phosphate; C- Carbon black; D- Graphite; E- Nickel-boron-silicon; F- Treated surface; G- Polished surface;

The bars containing straight lines represent the absorpitivity R_0; ▯- represents the hardness Hν; the bars containing slanted lines represent the laser heat treatment area S

zirconium oxide coating increases with increasing power density. However, the absorptivity of the carbon black coating decreases with increasing power density and it increases with increasing moving speed. At high power densities, because of the melting of metal surface, its absorptivity surges abruptly. At this time, coatings lose their function. At high moving speeds, absorptivity decreases with faster moving speed.

From Table 2 we know that effects on the laser treatrent results are not significant when the coating thickness is between 0.05 ~ 0.2 mm. However, when the thickness is about 1 mm, the treatment result decreases by a factor of 9. In addition, for coating materials which are easily combustible and melted, the coating should be thick. For high melting point non-combustible coating materials, it should be thin.

From Table 1 and Figure 7 we know that the zirconium oxide coating is number one in absorptivity under illumination at both low and high power densities. It is usually about 90%. The carbon black coating has a medium upper absorptivity at lower power densities (around 2000 watt/cm^2) which is uaually at about 80%. However, it is the last at high power density which is usually at around 50%. Under our experimental conditions, five coatings can cause the hardening of the metal surface. The effectiveness of hardening varies with the magnitude of absorptivity. When the absorptivity of the coating is high, the area of laser heat treatment on the substrate metal surface is large. Consequently, surface hardening is also high. All the metal surfaces treated and polished without coatings did not show any hardening effect.

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