Proceedings of the ASME 2016 International Manufacturing Science and Engineering Conference
MSEC2016
June 27-July 1, 2016, Blacksburg, Virginia, USA

MSEC2016-8515

A STUDY ON COPPER SURFACE PRE-TREATMENT AND WELDING WITH LASERS

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ABSTRACT

To improve the copper absorption coefficient to lasers, and to realize a high welding quality with a low power laser machine, a black-treating method was proposed in this study. With this method, the reflection coefficient of the copper to lasers with 1064nm wavelength could be reduced from 95% to 15.5%. The experimental study of copper welding with a 500 W fiber laser machine was carried out. The shape, the strength and the micro-hardness of the welding seam with different welding velocity and defocus amount were compared. And, the best welding parameter was obtained. Moreover, the laser welding quality of copper with black-treating and that with graphite coating was compared, and the result showed that the micro-hardness and the strength of the welding seam of copper with black-treating was better than that with graphite coating.

INTRODUCTION

The copper has excellent characters in electrical conduction, heat conduction, corrosion resistance and has been widely used in industry application. Copper welding is a hot international research topic, and lots of methods have been used to weld copper, such as friction stir welding, ultrasonic seam welding, plasma arc welding, and so on (1-5). Lasers with CW and pulsed mode were also used to weld the copper (6-8). Reflectivity of the metals is a main factor that determine the threshold of radiation intensity for laser material processing applications (9). The reflectivity of copper to lasers around 1000nm wavelength is higher than 95% (10). Realizing the copper welding needs a high power laser, and most of the laser energy was wasted. Even more, if the laser beam could not be controlled correctly, the optical system may be destroyed by the reflected laser. In order to improve the absorption coefficient of cooper to lasers, some experimental pre-processing procedures have been employed. Dadras et al. (11) used a preheating method to increase the laser energy absorption of the copper. Biro et al. (12) increased the effective absorptivity of the copper by increasing the oxygen content of the Argon (Ar) assist gas. The thin oxide layer on the weld zone surface significantly improved the effective material absorptivity. Dissimilar metals without filler materials using a 350W pulsed Nd:YAG laser were welded by butt joints within 1mm thick samples by Maiand Spowage (13). Mousavi and Niknejad (7) used the welding of copper beryllium plate with the nominal thickness of 0.2mm using butt welding. Another common method is coating graphite on the surface (9). With this method, the coating thickness could not be controlled accurately, and the welding seam was not well-distributed. Even more, the graphite may penetrate into the welding seam and affect the welding quality.

In this paper, a black-treating method was proposed to improve the absorption coefficient of the copper to laser beams. The technical process of this method was introduced detailed, and welding copper with a low power fiber laser was carried out. The welding seam quality, the welding strength and the micro-hardness was analyzed, and the copper welding quality with black-treating was compared with that with coating graphite.

SUFACE PRE-TREATMENT

The black-treating process was carried out on a high accuracy laser machining system (Fig.1). This system was combined with a 532nm nanosecond pulsed laser machine, a XYZ moving stable, a galvanometers optical scanner and the control system. A pulsed laser beam was generated form the laser machine and translated into the scanner, and the scanning path, the scanning speed was controlled by the control system through scanner.

In this study, a copper substrate with the dimension of 50mm×120mm×0.3mm was used. Before black treating, the substrate was stated on the working table, and was positioned by CCD system. Then, the copper was treated by a focused laser beam with 70um diameter. The average power of the pulsed laser could be changed from 2W to 10W, the frequency can be changed from 20KHz to 600KHz, and the pulse duration is 1.2ns. Through changing the scanning velocity, the path interval Δd and laser parameters, the thickness and the roughness of the black-treating area could be controlled accurately by this system.

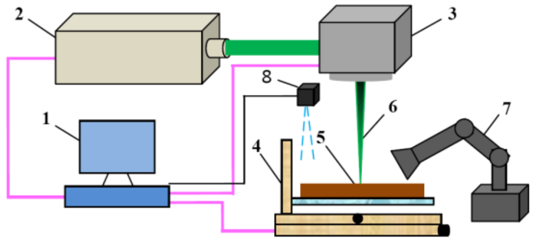


Fig.1 The black-treating system
(1. Control system, 2. Laser machine, 3. Scan head, 4.Moving system, 5. Copper, 6. Laser beam, 7. Dust absorbing system)

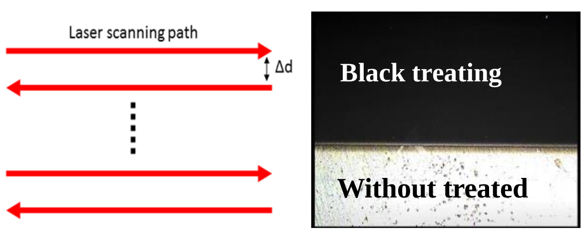
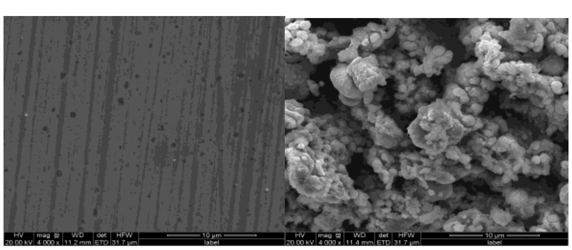


Fig.2 Copper black-treating surface

After black treated (the laser power was 8W, the frequency was 400KHz, the travelling speed was 2m/s, and the path interval Δd was 10um), the copper is blacker than that without treating. The black-treating area was cleaned by using a acetone, and tested by SEM (Fig.3). It found that there are lots of irregular micro-hops on the surface. When the laser beam irradiates on the copper surface, it is reflected lots of times in the micro-hops, and the absorption coefficient increases. On the other hand, an oxide layer was produced on the surface, which also increases the absorption coefficient.

In this study, a spectrophotometer Lambda-950w was used to test the reflective coefficient of copper with black-treating to lasers, and the result was shown in Fig.4.



(a) (b)

Fig.3 SEM 4000×
(a) Copper without treating, (b)Copper with black-treating

It is found that the copper without any treatment has a high reflectivity coefficient to 1064nm lasers, which is about 96.3%. Copper with graphite coating has a low reflectivity coefficient, which is about 6.2% to 1064 nm lasers. With the graphite-coating method, the copper could be welded with low power lasers, but lots of tiny graphite particles may penetrate into the welding seam and affect the welding quality. On the other side, the thickness of graphite coated on the cooper could not be controlled accurately.

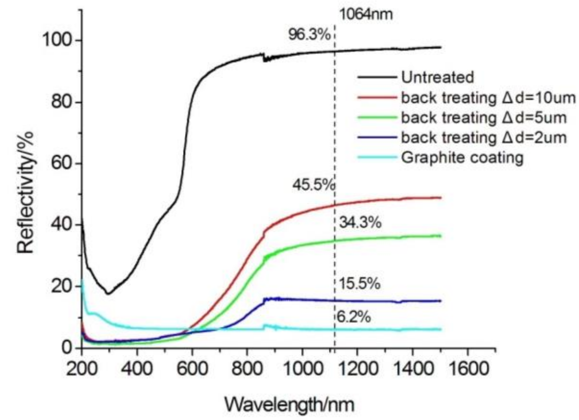


Fig.4 The reflectivity coefficient of copper to lasers with different wavelength after black-treating

The absorption coefficient of the copper with black-treating increases greatly compared with that without treatment. With the same laser power and the same scan velocity, the absorption coefficient was affected by the scanning interval greatly. The smaller of the interval is, the more copper oxide is induced, and the higher of the surface roughness is, the higher of the absorption coefficient is. However, with a much small interval, lots of problems were induced, such as a large thermal affect zone and the thermal deformation, which also affect the welding quality. So, for a particular thickness copper, there is the best interval. In this study, the best interval is 2um for 0.3mm thickness coppers, and the reflectivity coefficient of copper to 1064nm lasers is 15.5%.

COPPER WELDING

3.1 Experimental setup

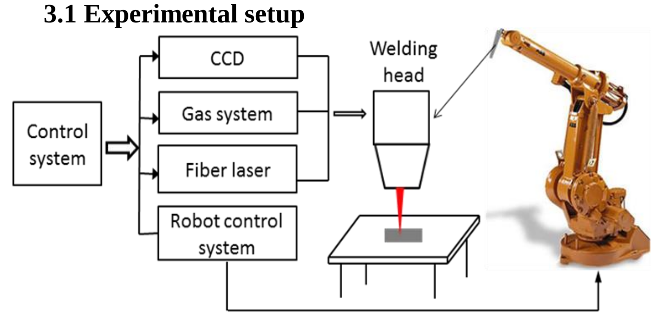


Fig.5 Copper welding system

In this study, a 0.3mm thickness black-treating copper with 2um interval was welded with 1064nm lasers. Fig.5 shows the laser welding system, which includes a 500W fiber laser, a six-axis robot system, a welding head, a CCD system, and a gas system. In this study, the high purity argon was used to protect the welding seam to oxidation, and the gas pressure is 0.1MPa. Two pieces of black-treating copper were lapped and clamped together. The welding path was positioned by CCD system, and welding parameters such as laser power, welding velocity, defocus amount were set by the controlling system.

3.2 Discussion

3.2.1 Welding seam shape

In this study, the effect of welding velocity and defocus amount to the welding seam shape was investigated under the same laser power 500W.

Table 1 gives the welding phenomenon with different defocus amount when the laser power is 500W and the welding velocity is 5mm/s. Through experimental study, it is found that the best welding quality was got when the defocus amount is 0 mm. When the defocus amount is ±2mm, because of the low power density, the copper substrate was penetrated incompletely. When the defocus amount is ±1 mm, lots of sparks appeared and micro-holes were induced in the welding seam.

Table 1 Welding copper with different defocus amount

Defocus amount /mm	Welding phenomenon
±2	not complete penetration, micro-holes in the welding seam
±1	lots of sparks appeared and micro-holes were induced in the welding seam
0	With orange flame, small welding width, uniform welding seam

Table 2 Welding seam shape with different velocity (laser power is 500W, defocus amount is 0 mm)

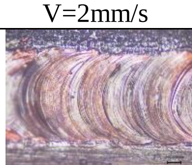
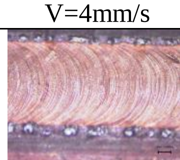
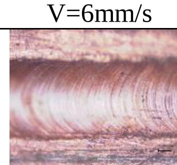
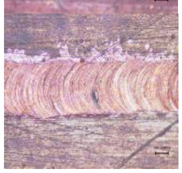
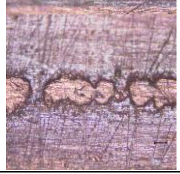
	V=2mm/s	V=4mm/s	V=6mm/s
Topside			
backside			

Table 2 gives the welding seam shape with different welding velocity when the laser power is 500W and the defocus amount is 0 mm. When the welding velocity is lower than 2mm/s, the laser energy absorbed by per length copper was too large to induce a large thermal affected zone. The copper melted overly, and lots of slags were attached on the back side of the welding seam. With the increasing of the velocity, the spatter disappeared gradually. When the welding velocity reaches to 4mm/s, the spatter disappeared completely, and a good quality welding seam was produced. With the further increasing the velocity, the laser energy absorbed by per length copper decreases, the width and the depth of the welding seam also decreases. When the velocity is 6mm/s, the copper was penetrated incompletely. Through experimental study, it is found that the best welding velocity is 4mm/s with the laser power 500W and the defocus amount 0 mm.

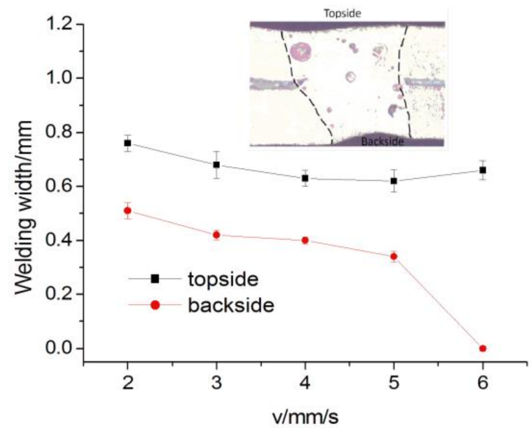


Fig.6 Welding seam wide changes with velocity

3.2.2 Welding strength

The welding strength was tested by an universal testing machine. From Fig.7, it can be obtained that with the increasing of the welding velocity, the welding strength increases firstly and then decreases. When the welding velocity is 2mm/s, some areas were melted through on the welding seam, which affects the welding strength greatly. With the increasing of the welding velocity, the welding seam becomes more uniform and the welding strength becomes higher. However, when the welding velocity is larger than 6mm/s, some incomplete penetration appears on the welding path, and the welding strength decreases rapidly.

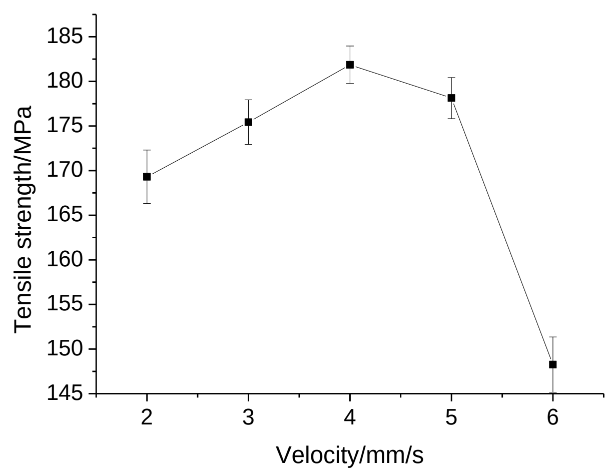


Fig.7 Welding maximum strength changes with velocity

Fig.8 gives the welding strength of the copper with black-treating and that with graphite coating. It is found that the welding strength of the black-treating copper is 181MPa, which is larger than that of the graphite-coating copper 132MPa. The break point is on the edge of the welding seam for black-treating copper, which indicates that the strength in the middle of welding seam is larger than that on the edge, and the black-treating has no effects to the welding strength. On the other hand, the break point is in the middle of the welding seam for graphite coating copper, which because the graphite penetrates into the welding seam and the strength was reduced.

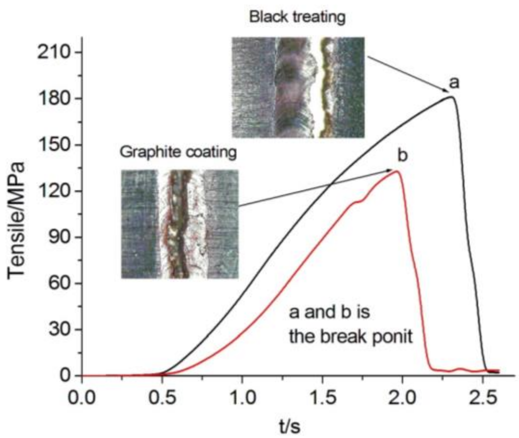


Fig.8 Comparation of the copper welding seam broken with black-treating and graphite coating

3.2.3 Micro-hardness

A micro-hardness instrument was used in this study, and the pressure head load is 50g, last 10 seconds. Two points in the middle and on the edge of the welding seam were chose to test the micro-hardness. From Fig.9, it can be found that with the increasing of the welding velocity, the micro-hardness increases firstly and then decreases. When the velocity is 4mm/s, the micro-hardness reaches the highest, which is 87.5HV and 82.8HV in the middle and on the edge of the welding seam, respectively.

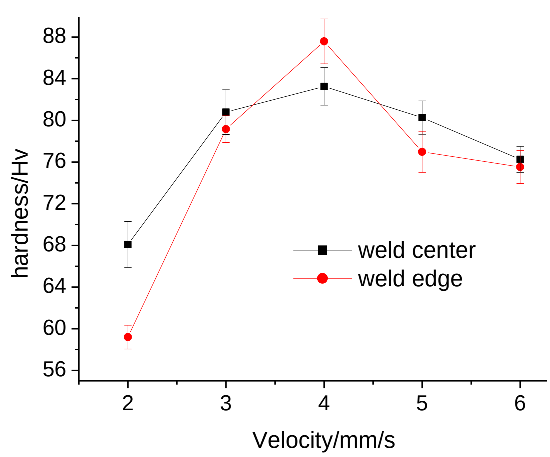


Fig.9 welding seam micro-hardness changes with velocity

Fig. 10 gives the welding seam hardness of copper with black-treating and that with graphite coating. For the black-treating sample, the highest hardness is 87.5HV in the middle of the welding seam, and it decreases with the increasing of the distance to the middle of welding seam. For the sample with graphite coating, the hardness in the middle of the welding seam is the lowest, which is 54.3HV, this because of the graphite penetrating into the welding seam.

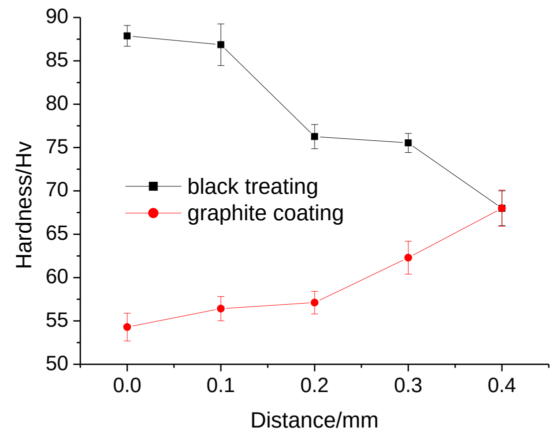


Fig.10. The comparation of welding seam micro-hardness with black-treating and graphite coating

CONCLUSIONS

In this study, a black-treating method was proposed to reduce the reflectivity coefficient of the copper to lasers. It is found that the reflectivity coefficient to 1064nm lasers can be reduced from 95% to 15.5%. After black treated, the copper sample was welded with fiber lasers. The shape, the strength and the micro-hardness of the welding seam under different welding velocity was investigated, and it is found that the best welding quality could be obtained with the welding parameters of 500W laser power, 4mm/s welding velocity and 0 mm defocus amount. The welding quality of the copper with black-treating and that with graphite coating was compared, and the result shows that the micro-hardness and the strength is higher for copper with black-treating than that with graphite coating.

ACKNOWLEDGMENTS

This work is supported by the Natural Science Foundation of Ningbo under Grant no. 2015A610078.

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