

Effect of scanning path on temperature field in laser cladding

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Abstract. Temperature field of planar laser cladding with length direction, width direction and helical scanning path were simulated and analysed. Temperature distribution could be effected significantly by the laser scanning path. For short-path scanning, heat was concentrated in the local area, resulting in larger (/smaller) temperature gradient in the length (/width) direction of the substrate. However, such characteristics of long-path scanning were on the contrary. By comparison, the heat affected zone (HAZ) of the substrate with helical scanning mode was the smallest and its temperature fluctuations were more dispersed.

1. Introduction

Laser cladding was an important application of laser processing technology, which could be used to the surface modification [1], manufacture of three-dimensional solid parts [2], and remanufacturing of damaged parts [3]. As fine microstructure, high strength of combined interface, small HAZ, laser cladding had many applications in aerospace, metallurgy, chemical, automobile, coal and other industries. Meanwhile, some basic researches related had been developed widely [4].

The temperature field, stress/strain field, microstructure/properties of the laser cladding process had coupling effects. The theoretical calculations of the latter two required the temperature solution to be introduced into the model firstly [5-6]. In the plane cladding process, warpage of the substrate would be affected by the laser scanning path. Thus, difference of temperature characteristics corresponding to multiple scanning paths, which were calculated by ANSYS software, was discussed in this paper.

2. Model Building

The planar laser cladding could be done with different scanning modes, such as long, short, and spiral path (Fig.1). Long (/short) path referred to grating movement of the laser beam along with length (/width) side of the processing plane. The spiral mode meant straight scanning of approximate helix, then such path from outside to inside was chosen in this paper.

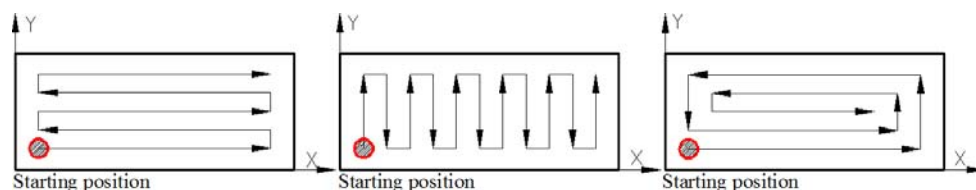


Figure 1. Schematic diagram of laser scanning (a) long-path, (b) short-path, (c) spiral-path.

Laser cladding of 316L stainless on 45steel substrate was set as physical model (Fig.2). To meet the actual working conditions, a large plate (45steel) was arranged under above substrate to transfer its internal heat. Size of the cladding layer, substrate, plate were set as 60 mm×20 mm×0.3 mm, 80 mm×25 mm×10 mm, 160 mm×50 mm×10 mm, respectively. Main process parameters were determined, such as laser power ($P=2000$ W), scanning speed ($V=4$ mm/s), powder feeding rate ($V_f=3$ g/min), overlap rate ($n=0$). Some other parameters of physical models corresponding to above three scanning paths were listed in Tab.1. The cladding process could be completed by three cycles of helical scanning, in which the single cladding length decreased with the number of scanning cycles (60 mm→52 mm→44 mm、12 mm→4 mm→0 mm), so the cladding time became shorter (15 s→13 s→11 s、3 s→1 s→0 s). Above parameters were all introduced into APDL programs of ANSYS software to complete the simulation calculation.

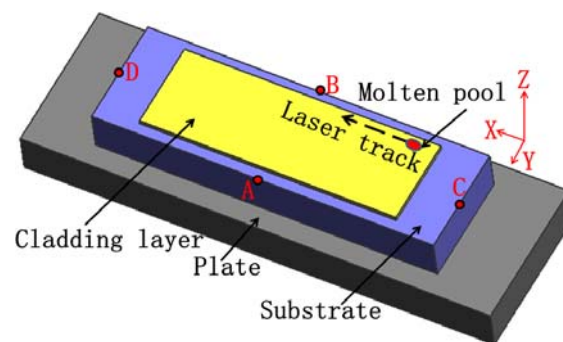


Figure 2. Physical model and distribution of key points.

Table 1. Physical model parameters.

	Long-path	Short-path	Spiral-path				
			1 st circle		2 nd circle		3 rd circle
Cladding area	60 mm × 20 mm						
Spot size	4 mm × 4 mm						
Scanning speed	4 mm/s						
Single track length	60 mm	20 mm	60 mm	12 mm	52 mm	4 mm	44 mm
Single track time	15 s	5 s	15 s	3 s	13 s	1 s	11 s
Cladding number	5	15	2	2	2	2	1
Total time	75 s	75 s	75 s				

In addition, meshing and mathematical model were similar to the literature [7], and unnecessary to go into detail.

3. Results and analysis

Temperature distribution of laser cladding in 20 s (a, d, g), 45 s (b, e, h), 75 s (c, f, i) corresponding to long (a, b, c), short (d, e, f), and spiral (g, h, i) scanning path were shown in Fig.3, respectively. Melting point of 316L stainless steel powder is about 1510°C, so the red zone (>1510°C) could be regarded as molten pool. Shape feature of each molten pool was stable and consistent with experimental phenomena, which presenting a nearly elliptical shape, so process parameters chosen in this paper were suitable. The green cloud diagram represented 600~900°C physical domain, and its long axis were consistent with the scanning direction, so a significant impact of scanning path on temperature field of cladding parts could be inferred. In addition, for above three models, low temperature region (<100°C) decreased and high temperature region (200~600°C) increased with the

cladding process (25 s $\rightarrow$ 50 s $\rightarrow$ 75 s), which indicating that the overall substrate trended to be warming and heat accumulated until the end of cladding.

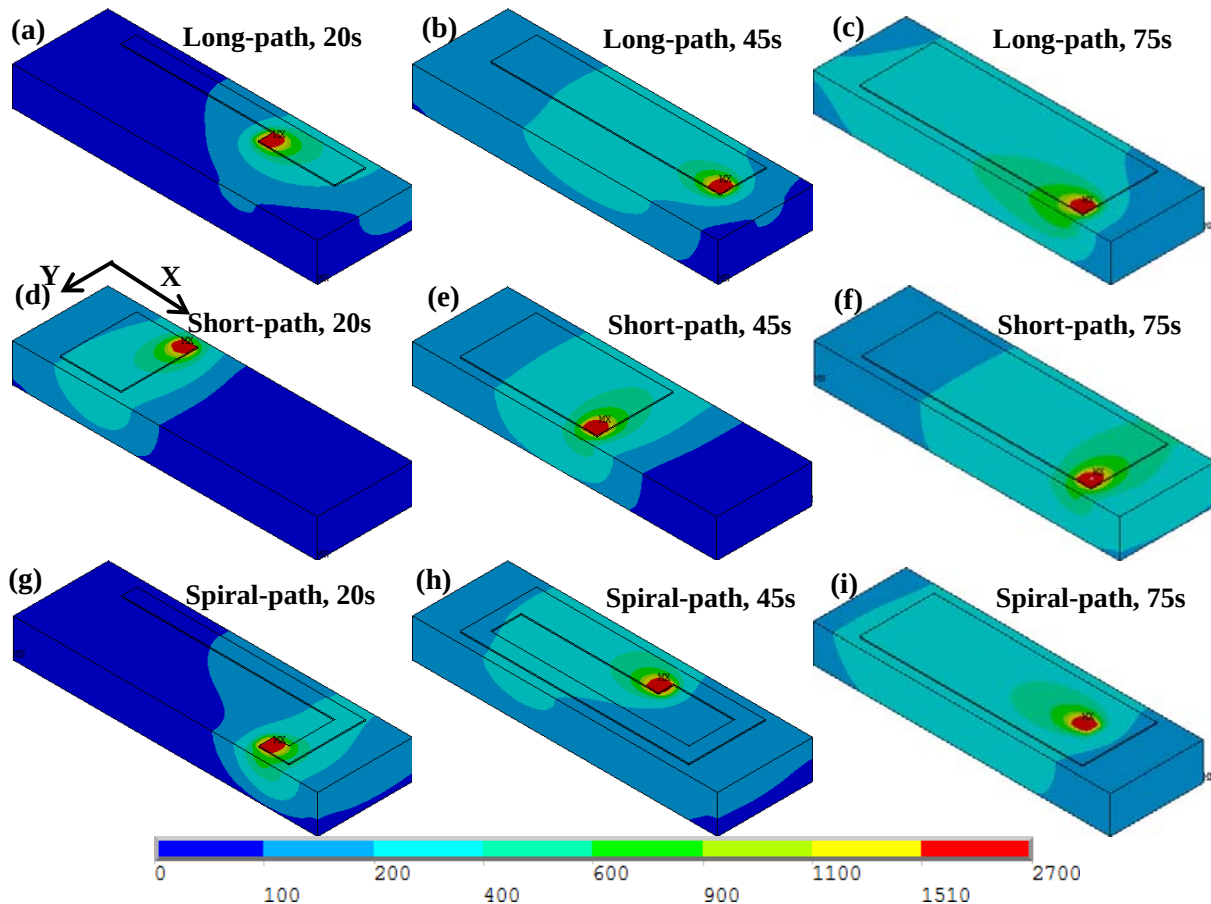


Figure 3. Temperature field distribution in 20s (a, d, g), 45s (b, e, h), 75s (c, f, i).

For short-path scanning, convective heat transfer surface of high temperature and direction of heat conduction were relatively scarce, so the heat was easily accumulated in the local area, which resulting in a large temperature difference in length-side (X-) direction, but even in width-side (Y-) direction. Temperature field characteristic of long-path scanning was just on the opposite. As alternate scanning direction ($X \rightarrow Y \rightarrow -X \rightarrow -Y \rightarrow \dots$), by which temperature contour was affected, temperature field for spiral-path would be a compromise distribution between long- and short-path models.

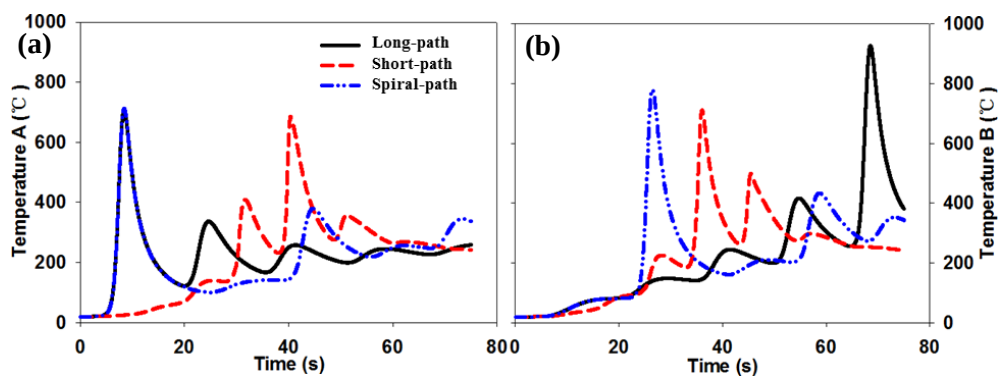


Figure 4. Transient temperature curve of point A, B.

Transient temperature curves of A, B point (Fig.2) during the entire cladding stage (0~75 s) were shown in Fig.4, and significant difference existed due to scanning path. The beginning and terminal in wide-side direction at middle region of the substrate were represented by A, B point respectively, which all going through temperature fluctuation for 3~4 times. As increased temperature of each trough, heat storage process in nearby regions for point A, B could be concluded. However, great difference existed in the time interval (T) of temperature peaks between the three scanning conditions, namely $T\text{-short} < T\text{-long} < T\text{-spiral}$. Peaks for short-path were concentrated in the time domain, but relatively dispersed for spiral-path, by which heat-affected zone near the substrate edge in width-side direction was the smallest.

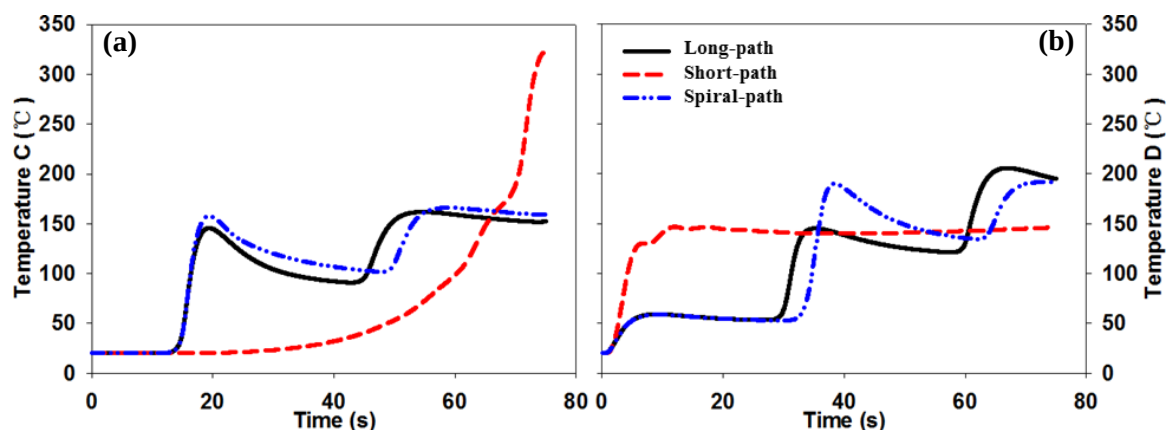


Figure 5. Transient temperature curve of point C, D.

Transient temperature curves of two substrate ends (C, D point) in length-side direction were illustrated in Fig.5, where similar temperature variation history was loaded for long-path and spiral-path models. During the whole cladding process, the laser beam moved to above ends 3 times, and the third peak of point C did not appear in the 0~75 seconds, so point C (/D) had experienced two (/three) thermal cycles. Temperature characteristics of the short-path model in these two regions were obviously different. Curves did not fluctuate with the reciprocating motion of the laser beam, which meant temperature variation reflected overall temperature rise of the substrate, rather than transient heating from the laser beam. In addition, the temperature at the beginning (point D) of laser scanning was constant after a brief temperature rise, where the heat conducted from the adjacent area could be offset by loss of surface convection. But the terminal (point D) experienced a long dormant period (0~40 s), slow (40~60 s) and accelerated (60~75 s) heating successively. According to this, a large temperature gradient existed in the length-side direction of the substrate.

4. Conclusion

The ANSYS software was used to simulate the laser cladding process with long, short, and spiral scanning path, and their temperature field were solved. By comparing and analyzing, the following conclusions were obtained.

(1) The isotherm of laser cladding model was elliptical nearly, and its long axis coincided with the moving direction of laser beam, by which a significant effect of laser scanning path on temperature field characteristics could be inferred.

(2) As the heat for short-path model being prone to accumulate in the local area, a larger (/smaller) temperature gradient existed in the length (/width) direction of the substrate. Characteristic of long-path model was just on the opposite.

(3) Effect on heat affect zone varied depending on the location. For substrate ends in width-side direction, the largest HAZ appeared in the short-path model, then long-path, spiral-path models were

in turn. And in length-side direction, the latter two models showed fluctuation characteristics of temperature rise.

Acknowledgments

Financial support from Basic Scientific Research Service Fee of Central University under the contract number of 3142015012 and 3142015097 are greatly appreciated.

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