Laser Surface Remelting of AISI 4140 Steel

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Abstract. In order to improve the surface wear resistance and hardness, laser remelting was used to process AISI 4140 steel. The microstructure and the Vickers hardness of surface and cross-section of those samples were studied. The results shown the laser power was one of the most important facts, which affect the enhanced hardness and microstructure. After laser remelting, the the grain size of the sample surface was refined, and the hardness of the melted surface of AISI 4140 was improved. Compared to the base material it has about 313% increase for samples processed with 130 W. It enhances the comprehensive mechanical properties dramatically.

1. Introduction

AISI 4140 is a kind of Medium hardenability structural alloy steel, which has many strong points, such as good manufacturability, good comprehensive mechanical properties after heat treatment. However, there are often oxide and sulfide inclusions in dendritic crystals, metallic compounds and other defects such as stomata in AISI 4140 steel. These defects will weaken the wear resistance and the hardness of the material when it exits on the surface.

Continuous scanning of metal material surface by high energy laser beam, which make a thin layer materials remelting on the top surface and it will be cooling fast and solidified almost immediately. This laser remelting process induced special fine microstructure and it will improve the surface properties of the materials to achieve better fatigue resistance, wear resistance and other properties [1, 2]. Moreover, due to the thin melting layer, the heat effect zone was small, and the remelting process has little effect on surface roughness and workpiece size, after laser remelting treatment, the workpiece can be used without other treatment.

For laser remelting is an economical fast and simple technology to improve the mechanical properties of many metal materials [3-5]. Study the microstructure and properties of laser remelted AISI 4140 steel, helps to further expand the use scope of 4041 steel products.
2. Experiments and Materials

2.1. Materials
The chemical composition of AISI 4140 was shown in table 1.

|                | Carbon   | Manganese | Phosphorus max | Sulfur max | Silicon | Chromium | Molybdenum |
|----------------|----------|-----------|----------------|------------|---------|----------|------------|
|                | 0.38-0.43| 0.75-1.0  | 0.035          | 0.040      | 0.15-0.35| 0.80-1.10| 0.15-0.25  |

2.2. Experiments
The selected laser parameters were: laser intensity (70W), beam size (0.8 mm), scanning speed (2 mm/s) and step size (0.25 mm). The samples were putted in a transparent chamber which was filled with floating N₂ gas in order to protect the samples form oxidation during laser remelting. An IPG fiber laser system was used in the laser remelting experiments at the frequency of 50 KHz, and the laser power 70 W, 90 W, 110 W, 130 W were selected, and the beam size is 0.8 mm, scanning speed is 2 mm/s and step size is 0.25 mm. Zeiss AxioVert. metallographic optical microscope and Hitachi SU5000 thermal field emission scanning electron microscope (SEM) were used to observer the surface morphology and microstructure of the samples. The HV-1000IS microhardness tester (Shanghai Jujing Precision Instrument Company) was used to measure the microhardness. The loading time was 5 s and the load was 500 g.

3. Results and Discussion

3.1. Surface Morphology and Microstructure
The surface morphology of different power laser remelting samples were shown in figure 1. Figures 1a-1d were samples surface remelted with laser power 70 W, 90 W, 110 W and 130 W wounded the same other experiment conditions. It can be seen from figure 1 that as the laser power increased the sample surface showed more obvious melting and solidified evidence. When the laser power was 70 W, the sample surface just melted a slight amount, and when the laser power increased to 130 W the surface was totally melted, and accordingly the surface roughness also increased with the laser power increasing.

Figure 1. Surface morphology of different power laser remelted AISI 4140 steel, (a) 70 W, (b) 90 W, (c) 110 W and (d) 130 W.
Figure 2 shows the section microstructure of AISI 4140 raw material and different laser power remelted 4140 samples. It can be found that, for the raw material, the whole section has the same microstructure, and for the laser remelted samples, each section metallography has three different zones: the surface melted zone, heat affected zone and base material. In laser melted zone the grain size was obviously fine for the rapid heating and cooling laser remelting process. And this rapid cooling process, which equivalents to a quenching process, significantly enhanced the mechanical properties of the surface layer.

During laser remelting process, due to the high temperature gradient, from the melted surface to the bottom of the sample, the microstructure was different. The melted zone after rapid cooling fine grain was obtained. And under the melting layer, there is the heat affected zone, here the temperature high enough to form austenite structure, and then as the temperature decreased rapidly, austenite structure transforms to coarse martensite structure, and it also has higher hardness then base material. For the base material zone, temperature rise was not enough to make the structure change, so it was kept as the raw material.

![Microstructure of different power laser remelted AISI 4140 steel](image)
3.2. XRD Analysis

XRD patterns shown in figure 3 indicated that after laser remelting the composition of the sample was not changed. It can be obviously found that the XRD patterns were similar. For different laser power remelted samples there is a new peak appeared at 43.5°, this maybe because of during the rapid laser melting and solidified process the alloy elements were floating to the surface.

![XRD Patterns](image)

Figure 3. XRD patterns of (a) raw material, (b) 70 W, (c) 90 W, (d) 110 W and (e) 130 W.

3.3. Microhardness

The surface hardness was measured. Figure 4 shows the average Vickers hardness of ANSI4140 raw material and 70W, 90W, 110W, 130W laser remelted samples. It can be noticed that as the laser power increasing the average hardness also increased. As the results show 130W has the highest average hardness.

![Microhardness Results](image)

Figure 4. Vickers hardness results.

Figure 5a shows the hardness at different position on the cross-section. It was measured from base material to the top remelted layer (figure 5b). It can be seen that the total tendency is the closer to the top melted layer the larger the hardness value. 70 W and 90 W laser power has similar results, meanwhile 110 W and 130 W laser power samples have almost the same results. As the laser power increasing the hardness values increased rapidly. It was calculated that for 70 W sample, compared to
the base material it has about 35% incensement; and for 90 W, has 23.14% incensement, 110 W, 286%, and 130 W, 313%. When the laser power great than 110 W, the samples hardness increased significantly.

Figure 5. (a) Cross-section Vickers hardness results, (b) schematic of the sample cross-section and the location of the Vickers hardness measured points.

4. Conclusion
(1) After laser remelting, the grain size of melted layer was significantly refined, and the surface hardness was increased with the laser power increase.

(2) In this study the samples remelted with 130 W have the best results the average Vickers hardness is 486, compared to the hardness of the base material (255 HV), has as big incensement.

(3) Laser remelting technology can be used to the surface modification of AISI 4140.

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