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Effect of laser tempering of high alloy powder metallurgical tool steels after laser cladding

Josu Leunda *,[1], Virginia García Navas, Carlos Soriano, Carmen Sanz

IK4-Tekniker, Advanced Manufacturing Technologies Unit, Polo Tecnológico de Eibar, Calle Iñaki Goenaga 5, 20600 Eibar, Gipuzkoa, Spain

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The effect of tempering after laser cladding of a high alloyed powder metallurgical tool steel was studied for die repairing purposes. In particular, a high power diode laser with scanning optics was employed for tempering. The laser tempering temperature was proven to be a critical factor in improving the mechanical properties of the coatings. In order to measure and evaluate the effect of different processing parameters (mainly laser power and linear speed) on the achieved temperature, an infrared camera and a two-color pyrometer were used. The tempering effect was mainly evaluated through cross-section microhardness profiles. The microstructure of the coatings was also studied using optical and scanning electron microscope, and the volumetric fraction of retained austenite was determined by X-ray diffraction.

Experimental results demonstrated that laser tempering is a useful and appealing technique to improve the hardness of laser deposited coatings of high alloyed tool steels, which is a clear advantage when large parts have to be repaired or reinforced by laser cladding.

1. Introduction

Laser cladding is a coating process that offers many advantages over conventional processes such as arc welding or plasma spraying. The laser cladding technique can produce a much better coating, with low dilution, minimal distortion and better surface quality [1]. Nonetheless, when depositing high alloy tool steels by means of this process, the resulting coatings usually show a relatively high volume fraction of retained austenite [2–7]. In fact, although it is generally accepted that processes with high cooling rates produce less amount of retained austenite, Colaço and Vilar demonstrated that increasing the cooling rate in laser surface melting of tool steels produces a refinement of the austenitic dendritic structure, thus increasing the amount of retained austenite [8–10]. Moreover, a transition from ferrite to austenite primary solidification may also occur as the solidification rate increases [8]. Such high retained austenite fractions are usually detrimental, especially when very hard coatings are needed, due to the low hardness of such microstructures. It is therefore compulsory to eliminate or transform the retained austenite into harder structures. This can be achieved either by subzero cooling or by tempering at a suitable temperature, although in the case of high alloyed tool steels the second approach produces best results, as retained austenite tends to be extremely stable. Moreover, the tempering treatment has the additional advantage of further increasing the hardness due to secondary hardening [8]. Some studies can be found in the literature regarding the reduction of the retained austenite fraction either by parameter control in laser surface melting [9–12] or by post-tempering in oven of coatings produced by laser cladding [13,14] or high energy electron-beam irradiation [15,16]. It is well known that some alloy steels that contain one or more of the carbide-forming elements (chromium, molybdenum, vanadium, and tungsten) are capable of secondary hardening; that is, they may become somewhat harder as a result of tempering. Furthermore, Colaço and Vilar [13], Rayment and Cantor [17] and Wu and Chen [18] have observed an increase of the secondary hardening tempering temperature in rapidly solidified structures in comparison with the conventional quenching and tempering treatments.

In the case of the high alloy powder metallurgical tool steel studied in this paper, i.e. HWS Isotropic, it had been proved in a previous work [14] that secondary hardening can be achieved by a triple tempering cycle in an oven, with a final temperature of 550 °C. Nevertheless, higher temperatures were proven to be detrimental not for the coating but for the base material, which was quenched and tempered in the traditional way, with a tempering temperature of 550 °C.

Taking these contradictory effects into account, a system for tempering the laser deposited coating at a temperature higher than the traditional one without negatively affecting the base metal would be appealing. In particular, heating the coating by means of a laser could produce temperature gradients sharp enough to reach the required temperatures in the coatings without exceeding the conventional tempering temperature in the base metal. Additionally, in the cases where the laser

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* Corresponding author at: IK4-TEKNIKERPolo Tecnológico de EibarC/ Iñaki Goenaga 520600 Eibar, Gipuzkoa (Spain).

E-mail addresses: josu.leunda@tekniker.es (J. Leunda), virginia.garcia@tekniker.es (V. García Navas), carlos.soriano@tekniker.es (C. Soriano), carmen.sanz@tekniker.es (C. Sanz).

[1] Tel.: +34 943 20 67 44.

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cladding technique is used for repairing large parts, this laser tempering method would provide a further advantage, as there would be no need of huge ovens and the dimensional distortions due to the thermal cycles would be completely eliminated, as just a localized region of the part would be treated.

To the best of our knowledge, this new approach for producing secondary hardening on laser deposited coatings by means of a laser source is yet to be studied. In order to fill this gap, this work was aimed to study the effect of the laser post-tempering of laser deposited HWS Isotropic layers, to demonstrate the feasibility of this process and to select the best parameters. The results obtained in the previous work [14] were taken as the starting point for the present study.

2. Materials and experimental procedure

2.1. Materials

Flat plates (150 × 70 × 15 mm) of heat treated HWS Isotropic (63–65 HRc), a powder metallurgical tool steel developed by Rovalma, were used as the substrate materials. The sample surfaces were ground before carrying out the laser cladding tests. Coatings were produced by means of laser cladding, employing gas atomized powder of the same material (HWS Isotropic), with spherical shape and a particle size of 45–90 μm. The chemical composition of this material is shown in Table 1.

2.2. Laser cladding

Multi-track coatings were produced by means of a CW Nd:YAG laser, covering an area of 60 × 15 mm, with a thickness of approximately 0.5 mm. All of the coatings were produced with the same process parameters, shown in Table 2 [14], by preheating the base metal to 250 °C in order to avoid cracking during cladding.

2.3. Laser tempering process and temperature monitoring

A CW diode laser with a maximum power of 10 kW was used for carrying out the post-tempering cycles of the coatings produced by laser cladding. The beam was guided by a circular fiber of 1 mm diameter and focused by a collimating unit and a focusing lens, producing a final focused top-hat spot of 8.3 mm diameter. A 2-mirror scanning system was placed immediately after the focusing lens, able to produce high speed oscillating movements of the laser spot. In this case, a scanning amplitude of 16.7 mm and a speed of 6000 mm/s were used in order to produce an *equivalent spot* of about 25 × 8.3 mm, as it can be observed in Fig. 1a.

The reason for using a different laser source for the tempering tests was the availability of a more adequate optical system for this source (larger spot and scanning head), although taking into account the dimension of the final laser spot and its power density, the Nd:YAG laser could in principle provide similar results just by replacing the laser cladding head with a proper scanning head.

The whole laser head was mounted in a 3-axis CNC machine that moved the *equivalent spot* in the direction perpendicular to its longest axis and along the cladding tracks, as it is schematically illustrated in Fig. 1b. The main processing parameters of the tempering tests are shown in Table 3.

Since temperature and irradiation time were expected to be the key parameters controlling the metallurgical processes that take place in the coatings and the base metal, pyrometry and infrared thermography were used for online monitoring of the temperature of the tempering process. On the one hand, by using a two-color pyrometer, realistic temperature measurements can be achieved, which does not depend on emissivity or other physical properties of the material. In this study, the spot of the pyrometer was manipulated by optics until achieving a circular spot of about 8 mm diameter, pointing directly at the center of the *equivalent laser spot* produced by the scanning optics. Nevertheless, nothing but the average temperature within the pyrometer spot can be achieved with this method, without providing information about the temperature distributions over the whole workpiece or cooling rates. The infrared thermography, on the other hand, may deliver this missing information, although in order to achieve realistic temperature values by means of this technique, the emissivity of the material has to be known, which depends on the actual temperature of the material, thus complicating the interpretation of the measured thermal images or thermograms.

Table 1
Chemical composition (wt.%) of the studied material.

Material	C	Cr	Mn	Mo	Si	V	W
HWS Isotropic	1.08	7.80	0.34	1.86	1.38	2.66	1.73

Table 2
Processing parameters used in the deposition of the coatings.

Laser power (kW)	1.2
Scanning speed (mm/s)	15
Powder flow rate (g/min)	5
Gas pressure (bar)	2
Overlap (%)	35

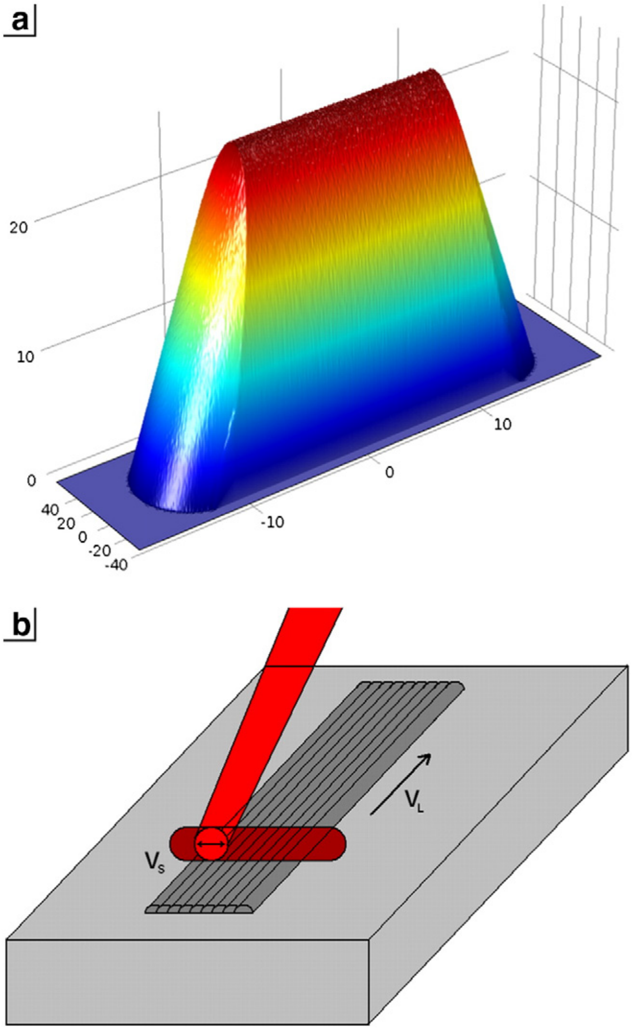

Fig. 1. (a) Calculated irradiance profile of the equivalent laser spot with scanning amplitude of 16.7 mm and a maximum speed of 6000 mm/s. (b) Scheme of the laser tempering process.