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Analysis of the regimes in the scanner-based laser hardening process

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ABSTRACT

Laser hardening is becoming a consolidated process in different industrial sectors such as the automotive industry or in the die and mold industry. The key to ensure the success in this process is to control the surface temperature and the hardened layer thickness. Furthermore, the development of reliable scanners, based on moving optics for guiding high power lasers at extremely fast speeds allows the rapid motion of laser spots, resulting on tailored shapes of swept areas by the laser. If a scanner is used to sweep a determined area, the laser energy density distribution can be adapted by varying parameters such us the scanning speed or laser power inside this area. Despite its advantages in terms of versatility, the use of scanners for the laser hardening process has not yet been introduced in the thermal hardening industry because of the difficulty of the temperature control and possible non-homogeneous hardness thickness layers.

In the present work the laser hardening process with scanning optics applied to AISI 1045 steel has been studied, with special emphasis on the influence of the scanning speed and the results derived from its variation, the evolution of the hardened layer thickness and different strategies for the control of the process temperature. For this purpose, the hardened material has been studied by measuring microhardness at different points and the shape of the hardened layer has also been evaluated. All tests have been performed using an experimental setup designed to keep a nominal temperature value using a closed-loop control. The tests results show two different regimes depending on the scanning speed and feed rate values. The experimental results conclusions have been validated by means of thermal simulations at different conditions.

1. Introduction

Laser hardening is a surface hardening treatment used in different sectors such as the automotive industry or in the die and mold sector. The main benefits of the laser hardening technology, compared to more traditional hardening processes such as induction or flame hardening processes, are the higher performance in 3D complex shapes with a minimum heat affected zone and much lower thermal distortions. As a consequence of these advantages, in some cases, it is possible to reduce or even eliminate final finishing operations [1]. In addition, the interest of this process lies in the possibility of direct integration of a laser heat source on the production line without an additional quenching medium, as well as the possibility to produce different microstructures in the part with a very accurate control between the treated and non-treated areas, resulting on a soft core with a hardened surface layer with compressive residual stresses in the surface [2]. This process is being used in the industry mainly for hardening stamping dies and molds. In particular, laser hardening is applied on the cutting edges of stamping dies, where it is possible to obtain a high surface hardness after the polishing operation with minimal geometric distortion. Laser hardening process is also being used in serial production of automotive components such us door hinges [1].

Laser hardening process can be considered a high speed surface treatment if it is compared with induction or flame hardening processes. Therefore, due to the high temperature gradients, the hardened layer thickness is usually between 0.8 and 1.5 mm, whereas conventional hardening process can reach values between 10 and 15 mm. This is because the thickness of material that reaches the austenitization temperature (T_{AC3}) is lower than in conventional hardening processes.

Furthermore, in recent years a series of systems based on moving optics and traditionally applied for laser marking operations, are being used for guiding high power lasers. These systems are also called scanners and they are can be coupled to the wrist of a serial robot [3] or in the spindle of a machine tool [4] in order to obtain a higher workspace. The main characteristic of the scanners is the ability to move and guide the laser beam with very high speeds (above 10,000 mm/s). The agility of the movements is obtained by the rotation of two mirrors,

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with very low mass and inertia.

The main advantages of scanners are the high processing speed and the working distance, which usually can be higher than 200 mm, and allows working far from the area to be processed. Currently, there are several research papers dedicated to the use of scanners in different manufacturing processes, particularly in the automotive industry such as marking, remote cutting or laser remote welding. Gradually these systems are being introduced in other industrial sectors such as the die and mold manufacturing industry where laser remote processes are being applied for texturing [5], polishing [6], drilling [7] or selective laser melting [8]. In contrast, the development of laser treatment processes based on scanning optics, also known as remote treatment processes, is still on a preliminary stage [9,10]. The main objective of this process is to move a laser beam rapidly, shaping the laser beam and obtaining a virtual shape (usually a line). With a conventional kinematics (Robot or Serial kinematics) the scanned shape is moved continuously on the hardened area. The main benefit of this variant is the possibility of adapting the size of the treated area at each point, unlike conventional laser hardening in which fixed optics with constant line widths are used. In the Fig. 1a 2D scanner scheme and the laser hardening scanning strategy is shown.

Some researchers have been performed experimental tests in order to evaluate the process capabilities [11–13]. These works present different results about the feasibility of the process, and all agree on the importance of the process parameter control. One of the most relevant aspects on laser surface hardening is the in-process temperature control requirement. The temperature of the surface must be continuously verified during the whole process in order to avoid surface melting while maintaining the temperature higher than T_{AC3}. In addition, the temperature control becomes much more difficult in the scanner-based laser hardening process since the beam moves rapidly. Therefore, the set-up of the temperature control loop is one of the most challenging aspects on the laser surface hardening process with scanning optics.

In conventional laser hardening the laser beam dimensions define the width of the area to be hardened, without any possibility of modification. Specific optics are designed to distribute the power density in the most appropriate way inside the beam. These optics, made individually by diamond turning, are unique and high cost parts, where a fixed laser beam size and shape is obtained [14]. On the other hand, laser hardening with scanning optics use a software-based control to change the width of the hardened zone. Therefore, the main advantage introduced by the laser hardening process with scanner optics is the geometrical flexibility. The use of scanning optics allows adapting the distribution of the laser energy density in a determined area by changing the laser trajectory and by varying parameters such us the scanning speed and/or laser power inside this area. By contrast, the main disadvantage presented by the scanning optics in laser hardening process can be the non-homogeneous transformations because of excessive working speed of the laser and temperature variations due to the scanning strategy. In an extreme situation, there is the possibility of not achieving the minimum temperature for the transformation or, if the energy density is too high, cause the partial fusion of the treated area.

One of the main parameters to obtain homogeneous transformations in laser hardening process is the energy density, which must be set to obtain the required hardened layer depth but without reaching the melting point at any point on the source. Therefore, the main objective is to find the best combination of parameters to keep the process temperature above the austenization temperature as long as possible and improve the depth of hardened layer, without reaching the melting temperature at any point.

As it can be observed in Fig. 1b, laser hardening with scanning optics process presents two different speeds, the scanning speed and the feed rate (which is 600–1000 times slower). One of the most characteristic parameters of this process is the scanning speed (V_S). It represents the guiding speed of the laser beam and it is controlled by the mirrors of the scanner, so the speed can reach up to 10,000 mm/s. On the other hand, the feed rate (V_F), which is the travel speed motion of the robot or machine tool, represents the speed of the hardened track on the part. During the scanning of the area to be hardened, while the machine moves to feed rate speed, the laser sweeps an area by moving the laser beam much faster. In Fig. 1b the continuous scanning strategy is shown as well as the thermal field generated in a point on the surface [15]. As it can be observed, the thermal field presents an inherent variation due to the scanning strategy. Therefore, the variation of the temperature could lead on non-homogeneous transformations.

Thus, in the present work, the strategies and parameters of laser hardening process with scanning optics will be studied, with special emphasis on the influence of the scanning speed and the results derived from its variation. The experimental tests have been focused on an AISI 1045 steel and different results have been measured such as microhardness, the shape and dimensions of the hardened layer and the loss

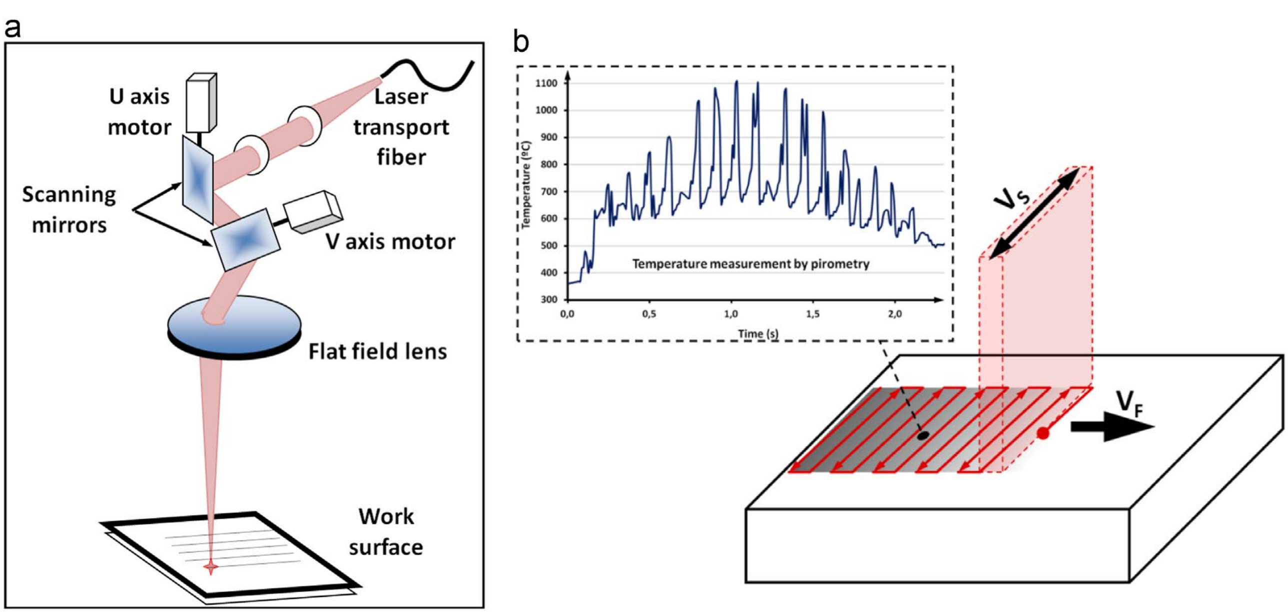

Fig. 1. a) A 2D scanner components; b) Continuous scanning strategy and thermal field generated in a point on the surface.