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Experimental investigations on fiber laser color marking of steels

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ABSTRACT

We develop an experimental approach with the aim to bring a contribution to the comprehension of the occurring phenomena during laser color marking of steels. A home-made marking device using a pulsed fiber laser has been used to treat steel samples under different laser beam operating parameters, for different compositions of the processed steel, and at normal atmospheric conditions. The treated samples were analyzed either by optical and scanning electronic microscopy, as well as by energy dispersion spectroscopy. The results show the influence of the operating parameters on the obtained colors.

1. Introduction

Nowadays, the modern technologies and the related industries are in continuous development, and the marking of the made products is becoming essential for many reasons. Within the reasons that have led to marking products in manufacturing industries, improving security and efficiency, mainly when it is used for serial or batch production numbers, for 2D matrix codes to fight against infringement. . .[1–4]. More, colors production on metallic surfaces represents a specific process that is achieved for particular applications, since color could be a key potential differentiator. Among the conventional techniques that are used for color marking of metals, the chemical treatment is considered as the oldest industrial technique [1]. The obtained films are however characterized by structural weakness and porosities occurrence, and an electrochemical treatment is necessary to fix the colors [5]. Otherwise, the treatment by thermal oxidation is also used to color stainless steels at high temperature which could be more than 500 °C. These conventional techniques often based on thermo-chemical treatments can damage the material and moreover lead to the generation of important quantity of secondary waste which must be recycled afterwards.

A close control of heat input is therefore essential to avoid material structural damages and to obtain higher quality products. In this context, the laser beams whose main features are their monochromaticity, directivity and spatio-temporal coherence, constitute a solution to achieve a controlled heat input on materials surfaces. The process of laser marking can mainly be achieved by two methods. The marking by mask, and scanning laser marking. In marking by mask, the focused laser beam get through a mask before lighting the surface of the workpiece, where complex shapes of the mask image can be projected over the material surface by an adapted optical set up. Generally, this marking method requires the use of high energy pulsed laser beams [6]. The other method consists in displacing the focused laser beam on the workpiece surface by the mean of two galvanometric mirrors, where each mirror deflects the laser beam in a given direction. By an adequate control of the mirrors, it is possible to obtain the wanted trajectory of the laser beam. In regard to the classical methods of metal color marking, the advantage of using a laser source is that it allows a very local modification of the physico-chemical properties of the sample surface, without producing changes on the bulk material properties. This advantage permits the generation of various colors on small surfaces.

It is pointed out that under normal atmospheric conditions, the aspect modification during laser beam heating of the material surface and colors generation, results in the oxidation of the metallic surface. Accordingly, obtaining given colors is related to the laser beam operating parameters, the metallic workpiece physical properties, and the environmental conditions. The main operating parameters are the beam power, the scanning velocity, the beam frequency, the beam spot diameter, and to obtain a given output characterized by a desired color, several experiments must be conducted by varying the laser beam operating parameters. However,

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Fig. 1. The used homemade device for metals laser marking.

the number of the necessary experiments with identified process parameters can be reduced by using a design of experiments (DOE) method [7].

It is worthwhile to mention that in literature, the number of research papers that were devoted to the investigations and the understanding of the laser marking process mechanisms is quite limited compared to the other laser processes. The possible reason is that metals laser marking is among the recent lasers applications [8,9], it is indeed reported that using of lasers to produce colored marks go back at the late 90s, when niobium bowls had been laser color marked establishing that the technique was suitable for ornamentation of craft metal work and jewelry [10]. Most of the studies were performed by using Nd:YAG, and fiber lasers, in order to determine the effect of the process parameters on the surface roughness, the surface reflectance, the mark contrast and

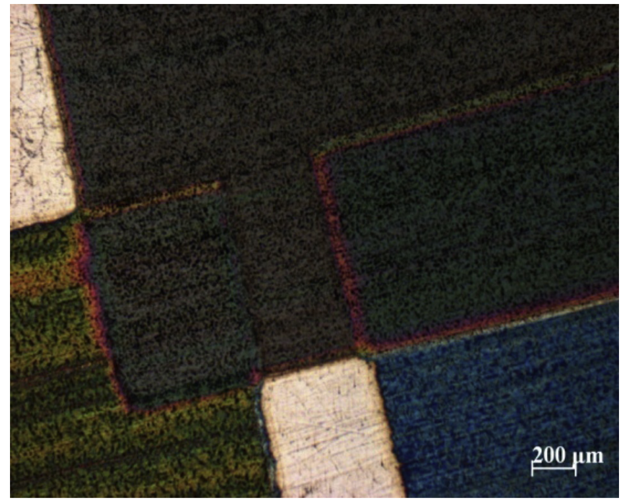

Fig. 2. The different colors obtained for different operating parameters on the same workpiece.

the depth of removed material. Some authors suggested that the surface metallic coloration is related to the composition of the bulk oxides color [11–14]. Lemuskero et al. [15] obtained colors on stainless steel by heating the surfaces with fiber laser, they have modeled the colors as an effective sum of small color pixels and presented a qualitative relation between the energy, the color, and the oxide layer thickness. Campanelli et al. [16] investigated the effects of operating parameters such as scan speed, pulse frequency, beam power, overlapping degree, on the surface roughness and the depth of material removal. Leone et al. [17] used a Q-switched diode-pumped Nd:YAG green laser to study the influence of multiple laser scanning, the pulse frequency and the scanning speed on the material removal rates for different types of wood. Using a Q-switched Nd:YAG laser equipped with a galvanometric head, Soveja et al. [18] investigated the effect of the repetition rate, the pulses energy, the scanning speed and the line-spacing on the mark surface roughness, on the material removal rate and on the composite function. They found out that, only the repetition rate and the energy of pulses have a significant influence on laser surface texturing process. Cicala et al. [19] studied the limitations of metals laser machining and quantified through a DOE the influence of the operating parameters on productivity and on the quality of the processed surface. On the case of colors control investigations, Lavisse et al. [20] studied the effect of laser fluences, ranging from 4 to 60 J/cm^2, on the color of the marked surface, its roughness and its morphology. It was found out that the color of the layers was changing from colorless to yellow for low laser fluences, and from purple to blue for higher ones. It was noted that at low fluences, the laser pass induced scars and cracks, but the surface layer was smooth, and at higher fluences, the sample surface was very rough. Perez Del Pino et al. [21] studied the influence of the scanning velocity on pulsed laser induced oxidation of titanium under normal atmospheric conditions. The SEM characterization showed that during treatments, melting and re-solidification processes lead to the formation of a bi-layer structure composed of a compact layer covered by a thin granulated layer. Compositional analyses performed with XRD and Raman spectroscopy showed the formation of several titanium oxides depending on the accumulated energy.

In the present contribution, we propose an experimental study of stainless steel color marking by a fiber laser. The aim of our work is to identify the physical mechanisms occurring in the formation of the oxide layers, which are responsible of colors formation on