Achievements in Mechanical and Materials Engineering

COMMENT Worldwide Congress on Materials and Manufacturing Engineering and Technology

16th - 19th May 2005 Gliwice-Wisła, Poland

COMMITTEE OF MATERIALS SCIENCE OF THE POLISH ACADEMY OF SCIENCES, KATOWICE, POLAND
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ASSOCIATION OF THE ALUMNI OF THE SILESIAN UNIVERSITY OF TECHNOLOGY, MATERIALS ENGINEERING CIRCLE, GLIWICE, POLAND

13th INTERNATIONAL SCIENTIFIC CONFERENCE ON ACHIEVEMENTS IN MECHANICAL AND MATERIALS ENGINEERING

Comparison of the structures of the hot-work tool steels laser modified surface layers

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Abstract: The paper presents comparison between structure and properties of remelting and alloying the X40CrMoV5-1 hot-work tool steel surface layer using the high power diode laser (HPDL). The tungsten carbide powder was used as an alloying material. The X40CrMoV5-1 conventionally heat treated steel was used as reference material. The structural mechanism was determined of surface layers development. It has the important cognitive significance and gives grounds to the practical employment of these technologies for forming the surfaces of new tools and regeneration of the used ones.

Keywords: hot-work tool steel, surface layer, gradient coating, remelting, alloying, high power diode laser

1. INTRODUCTION

Forecasts pertaining to the global economic development factors regard laser manufacturing techniques as the most promising and efficient ones for ensuring the development in many industry branches in which materials processing dominates. It is considered that in future only these economies will be competitive in the global market in which laser technologies will be widely used [1, 3-6]. No other materials processing technology development is funded to such extent and worked out with such concentration of efforts of the research institutes as laser technologies [2]. Laser radiation features currently the state-of-the-art source of heat energy, used to form structure and properties of the surface layer. There is an opinion that laser manufacturing techniques belong to the most promising and efficient ones, for ensuring the development in many industry branches, and especially those in which materials processing dominates. Thanks to the very precise energy delivery laser radiation makes it possible to carry out the technological operations better or faster within the framework of the technologies known to date. It makes also possible introduction of the new technologies whose realisation is impossible when using the conventional power density [2].

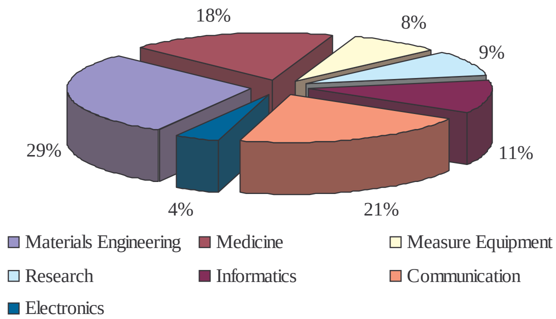

Figure 1. Employment of laser technologies in various branches of the world economy [2, 6]

The world industry already makes widely use of laser technologies (Fig. 1) and the most extensive industrial use in the laser materials processing have currently the solid state lasers with the Nd:YAG crystal active element and the CO_2 gas lasers. In laser remelting and alloying processes heat is transported away from the surface by thermal conduction, inducing rapid cooling [1, 5-6]. Austenitized material, provided with sufficient quantities of carbon, forms martensite on quenching, producing a hard and wear resistant surface. The properties of the hardened layer are controlled by the energy input, which depends on the beam power density and interaction time. Long interaction times enable more heat to be conducted into the material before the melting temperature is attained at the surface, thus producing a deeper hardened layer. Higher traverse rate and power density result in a faster cooling rate, at the expense of the depth of the hardened layer. The geometry of the hardened layer depends on the processing parameters and beam-matter interaction, and their effect on the thermal cycle induced by laser radiation. Consequent phase transformations, which determine the hardness of the resulting microstructure, are affected by material composition, initial microstructure and processing parameters. The advantages of laser treatment in comparison to other surface layer modification methods are: fast treatment, possibility to carry out the treatment without shielding facilities, modification of small – freely selected surface fragments responsible for tool and machine elements life, as well as materials economy. However, its disadvantages are the relatively high purchase cost of the high power lasers and high surface roughness after laser treatment.

2. EXPERIMENTAL PROCEDURE

The experiments were made on specimens made from the X40CrMoV5-1 alloy hot work tool steel. The specimens were austenitized on the salt bath furnace and tempered in the chamber furnace in the protective atmosphere – argon. The specimens were gradually heated to the austenitizing temperature with the isothermal stops at 650 and 850°C for 15 min. Further they were austenitized for 30 min at the temperature of 1060°C and cooled in hot oil. The specimens were tempered twice for 2 hours at the temperature of 510°C after quenching. Next, powder layers of the WC tungsten carbide of two different thicknesses of 0.06 mm and 0.11 mm bounded with the inorganic binding agent were put down onto the degreased specimens. Specimens of the X40CrMoV5-1 steel fixed in a turntable were remelted with the Rofin DL 020 high power laser beam (HPDL). The dimensions of the laser beam focused on the material surface are 1.8 x 6.8 mm. The multimode energy distribution was used. It was found out in the preliminary investigations that the maximum feed rate at which the process is stable is 0.5 m.min. Further experiments were carried out at the constant remelting rate, changing the laser beam power in the 0.5-2.5 kW range during remelting the surface layer of the test pieces, and in the 0.5-1.9 kW range during alloying the test pieces. It was established experimentally that the argon blow-in with the flow rate of 20 l/min through the ϕ 12mm circular nozzle oppositely directed in respect to the remelting direction provides full remelting zone protection. The test pieces were machined after remelting and alloying, to remove the non-remelted layer of the tungsten carbide.

Temperature measurement during laser remelting was carried out using Ratek Marathon Series pyrometer with the 700-1600°C operating temperature range. Two measurement variants were used: the reciprocal pyrometer and the material remelting beam movement and the laser beam treated specimen moving independently from the stationary pyrometer.

Metallographic examinations of material structure after laser alloying of its surface layer were made on Leica MEF4A light microscope at magnifications from 100 to 1000x. The Leica – Qwin computer image analysis system was used for thickness examination of the particular zones of the surface layer and for measurement of grain areas and dendrite lengths. Grain size analysis was carried out on the steel microstructure images saved in the electronic form. The stored examination results of the average grain size and dendrite lengths in the particular zones were analysed statistically. The X-ray qualitative and quantitative micro-analysis and analysis of the surface distribution of the alloying elements in the test pieces of the investigated steel, subjected to the standard heat treatment and remelted and alloyed, were made on the Opton DSM-940 scanning electron microscope with the Oxford EDS LINK ISIS X-ray energy dispersive spectrometer at the accelerating voltage of 20 kV and on the JEOL JCXA 733 X-ray micro-analyser. The crystalline X-ray wavelength dispersive spectroscopes (WDS) were used for quantitative analysis, using the accelerating voltage of 20 kV, and 10 kV during carbon analysis.

3. ANALYSIS OF EXPERIMENTAL RESULTS

The direct connection of the laser radiation effect on the surface layer temperature of the investigated steel was found by pyrometer measurements of the temperature changes of the material surface subjected to laser beam impact. The dynamical temperature increase was revealed in the remelting location, reaching by the material the temperature higher than the solidus, and a quick temperature drop after laser beam transition, caused by transferring the heat from the remelting area to the quasi-infinite volume of the native material. Employment of the concurrent temperature registration in the remelting area proves that the laser surface layer modification process proceeds relatively smoothly. Temperature changes plot during remelting is shown in Figure 5. Roughness of the surface layers obtained by remelting the steel with the laser beam with the power from 1.1 to 2.5 kW is within the range of R_a = 0.91-1.76 μm and grows proportionally to the laser beam power. The initial experiments with alloying the X40CrMoV5-1 hot work alloy tool steel indicate the clear effect of the alloying process parameters, especially the laser beam power, on the run face shape. Increase of the laser power, thickness of the tungsten carbide layer put down onto the steel surface before remelting, and decrease of the laser beam feed rate result in the increase of surface roughness and shape irregularity of the run face. This effect is connected with the increase of laser radiation absorption by the specimen surface, due to the high tungsten carbide absorption coefficient. Absorption increase causes growth of the steel surface layer remelting process intensity.

4. SUMMARY

Experiments of remelting and alloying with tungsten carbide the X40CrMoV5-1 hot-work alloy tool steel indicate to the clear influence of the remelting and alloying processes' parameters, especially of the laser beam power, on the bead face shape. Treatment in the analysed laser power range ensures the regular and flat face shape, with no partial melting and with the relatively high surface quality. A small number of depressions and surface irregularities, resulting from its intensive heating occur on paths developed during laser alloying of the surface layer. Material transport in the molten metal, caused by surface tension forces features the main factor deciding development of the alloy layers. Increase of the laser power during remelting and of the thickness of the tungsten carbide coating put down onto the steel surface at the constant laser beam feed rate cause increase of roughness and irregularity of the beam face shape. This effect is connected with the increase of the laser radiation absorption by the test piece surface, thanks to the higher value of the tungsten carbide absorption coefficient compared to the steel surface absorption coefficient.

ACKNOWLEDGMENTS

Investigations were partially financed within the frameworks of the Polish State Committee for Scientific Research No 4 T08C 051 25 grant headed by Dr. E. Hajduczek and PBZ-100/4/T08/2004 headed by Prof. L.A. Dobrzański. Authors participate in the CEEPUS No PL-013/04-05 project headed by Prof. L.A. Dobrzański.

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