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Laser heat treatment of low-alloy steels

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ABSTRACT:

In this paper, the possibility of increasing the wear resistance of 40KhN2MFA steel via usage of laser heat treatment (LHT) is considered. During the study, it was determined that after LHT, the wear resistance of the parts increases by 2-3 times in comparison to the base metal in the normalization state. This allows the authors to recommend the developed LHT technology with minimal surface melting for industrial usage, specifically, to increase the service life of thelarge diesel engine crankshafts. It has been established that the presence of a minimal (to a depth of up to 0.1 mm) melting of the middle part (5-6 mm wide) of the surface of the melting tracks during LHT allows for an increase in their depth to 1.0 mm with a total track width of 8-9 mm. To eliminate cracking of the hardened surface of the crankshafts made out of 40KhN2MFA steelduring LHT, it is advisable to apply the process tracks with a1-2 mm gap, as well as to perform volumetric heat treatment of parts after theLHT process itself. Such heat treatment includes heating up to 220-250°C for 3-4 hours with subsequent air cooling. In conclusion,LHT of 40KhN2MFA steel makes it possible to increase wear resistance only formachined parts that operate under relatively low (up to 200°C) temperatures. At the same time, the heat resistance of the steel under consideration does not increase at the higher operating temperatures, and at the 540–570°C, the heat resistance effect, provided by the LHT, disappears completely.

NOMENCLATURE

Symbol	Description	Unit
P	Laser power	*kW*
v	Speed of laser radiation movement	*m/s*
d	Laser radiation diameter	*mm*
σ	Compressive stress	*MPa*
HRC	Rockwell hardness standard	
t	Focus depth	*mm*

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I. INTRODUCTION

Inmachine industry, hypoeutectoid complex alloyed steels are often used for the manufacture of complex and critical parts[1–3]. For example, they are used for the manufacture of crankshafts of powerful automobile and marine diesel engines (GOST 40KhN2MFAsteel - the material, from which the truck crankshafts are made), parts of steam turbinesteam distribution equipment (GOST25Kh1M1FTRsteel), turbogenerator rings (GOST 38KhN3MFA steel). To increase wear resistance, parts made of these steels are hardened by traditional methods (for example, volumetric heat treatment in furnaces, chemical-thermal treatment, high-frequency hardening). However, the service life of such parts is not always satisfactory. Due to the relatively high cost, the task of increasing their service life by 1.5-2 times is urgent. It is believed that the additional operation of thermal hardening is economically justified, the cost of the hardening carried out should not exceed 10-30% of the cost of the hardened partitself.

An increase in the service life in the case under consideration can be achieved by various methods (plasma detonation [4-7], ion-plasma [8], electroplating, etc.). Hardening with usage of various highly concentrated energy sources has proven itself well in cases of usage of laser [9-15], electron-beam [16-18] and plasma [19-21] sources. Of these methods, laser heat treatment (LHT) differs from othersfavourably in its high locality and productivity, and the absence of the need for processing in complex vacuum chambers [9]. Thus, LHT is acceptable for solving this problem.

The LHT process can be carried out with or without melting of the hardened surface. In the first case, quenching zones from the liquid and solid phases are observed along the depth of the LHTtrack. In the second case, quenching occurs only in the solid phase. The choice of variousoptions provided by LHTmay depend on the dimensions and purpose of the hardened part, the acceptability of finishing machining, the material of the part, etc.

II. PURPOSE OF THE STUDY. TASKS, CARRIED OUT DURING THE STUDY

The purpose of this study was to study the possibility of improving the performance of crankshafts of large diesel engines by using laser heat treatment.
To achieve this purpose, the following tasks were solved:
1. Conducting technological research and selection of laser heat treatment modes for crankshafts made of 40KhN2MFA steel.
2. Carrying out metallographic studies of individual scanning tracks in laser heat treatment, studying the resulting structures and their features.
3. Study of the residual stress state of LHT scanning tracks and development of approaches to minimization (elimination) of stresses.
4. Study of the change in the level of wear resistance of the surface of specimens made of GOST 40KhN2MFA steel after the LHT process was carried out.

III. EXPERIMENTAL SETUP

During the study, laser heat treatment of GOST 40KhN2MFA steel was studied in order to increase the hardness and wear resistance of crankshafts in case of operation at a normal temperature for a diesel engine (about 90°C), as well as LHT of GOST25Kh1M1FTR steel to harden the internal and external surfaces of control parts of steam distribution and control equipment (valves, bushings, rods) of steam turbines operating at 540-570°C and at pressure of up to 12 MPa.
GOST 40KhN2MFA steel was hardened to a 0.8-1.0 mm depth in a 6-9 mm wide spiral path with a 1-2 mm distance between the turns. In order to obtain laser heat treatment technology that provides a homogeneous structure and isotropic properties, hardening was carried out without melting. Since the allowance for finishing refinement by grinding of the hardened necks was 0.1 mm per side, in order to increase the stability of the LHT process, the presence of a melting zone of up to 0.1 mm in depth was allowed. The task mandates the resulting hardness of the tracks in the HRC 54-59range, with the hardness of the base metal in the HRC 40-45 range. When using GOST 25Kh1M1FTR steel, due to its technological usage a requirement to obtain a at least 0.5 mm deep surface layer with a hardness of at least HRC 48, when the base metal hardness is located in HRC 20-23 range. To this end, a variant of LHTprocess with complete remelting to such a depth was adopted.
The experiments were carried out on a technological CO2 laser and a rotator based on a FT-11 lathe. Samples used in tests included: ∅80×60 and ∅95×40 mm samples of truck crankshafts made of GOST 40KhN2MFA steel as well as∅100×∅60×50 mm bushings made of GOST25Kh1M1FTR steel. To improve their absorption capacity, the polished crankshafts imitator samples were coated with Zn3(PO4)2 using cold chemical etching.
As a result of laser heat treatment testing onGOST 40KhN2MFA steel, the following mode was chosen: P=3.2 kW, v=16.67 mm/s, d=8 mm. Tests were carried out with a focus depth t=60±5 mm (lens focal length = 300 mm). For laser heat treatment of GOST 25Kh1M1FTR steel, the following mode was chosen: P=1.5 kW, v=23 mm/s, d=1 mm. Processing was carried out near the focus.

IV. RESULTS AND DISCUSSION

As a result of the testing, it has been established that during laser heat treatment ofGOST 40KhN2MFA steel with a 8–9 mm single track width led to a creation of5–6 mm wide melted zone with 70–100 µm depth.The total track depth in this case reached values of 0.8–1.0 mm. During experiments in which no melted zone was created, the maximum depth of the single laser heat treatment track reached 0.7-0.8 mm. The base metal has a bainitic structure (mainly lower bainite) with characteristic forging bands. The structure of the melted (cast) zone is clearly expressed as dendritic, in which 10–20 µm wide microcracks can form.They remain within the cast zone and do not propagate into the hardening zone from the solid phase, which makes it possible to eliminate them together with the allowance during finishing machining. The quenching zone from the solid phase is a structureless (rarely finely acicular) martensite with uniform HRC 65-66 hardness. Between the quenching zone and the base metal, a 40-60µm wide transition zone, where a smooth drop in hardness in hardness was noted, exists.
The presence of microcracks in the cast zone indicates the effect of temporary thermal stresses in the laser heat

treatment process. Using a DRON-3 X-ray phase analyser, first-type zonal macrostresses of the were measured in the laser heat treatment tracks utilizing X-ray diffraction analysis. It was determined that compressive stresses of σ=763 MPa ± 380 MPa take place on the surface of the laser heat treatment tracks without melting (in GOST 40KhN2MFA steel). Compared to the tensile strength, these stresses are significant and in combination with cyclic alternating loads, characteristic of the operating conditions of the crankshaft, leading to premature failure of the part. Residual stresses were not detected in the melted (casting) zone of the laser heat treatment tracks. Volumetric heat treatment of samples made of GOST 40KhN2MFA steel after laser heat treatment, which includes heating it to 220–250°C, holding it in this state for 3–4 h with subsequent air cooling, allows for possibility of complete elimination of residual stresses. The hardened steel hardness of is therefore reduced to HRC ~60.

Tests of laser heat treated samples of GOST 40KhN2MFA steel for wear resistance by dry friction were carried out on a specially manufactured friction machine, according to the cylinder-pin scheme. The counterbodies for this machine were made of steel 45 followed by hardening to HRC ~55. The specific pressure was set at 10–16 MPa, the number of revolutions of the sample was variable, in the range of 50–1600 min^{-1}, and the friction rate was 1600–54000 m/h. Wear was measured with a micrometre with 0.01 mm accuracy margin as well as by weighing on an analytical balance with an accuracy of ±10 mg. To improve the measurement accuracy, the friction time was increased. Compared with samples from a standard crankshaft, the resistance of samples, where laser heat treatment was carried out, was increased by 2-3 times.
During the laser heat treatment of GOST 25Kh1M1FTR steel track depth of 0.7-0.9 mm with a 1.1-1.3 mm width was achieved. For avoidance of the dangerous overlap, a 0.2-0.3 mm distance between single tracks was established. During testing, the cast zone hardness was measured to be in range of HRC 48-54. The maximum measured width of the transition zone was equal to 40 μm, its hardness varying in HRC 30-35 range. The hardened bushings were tested for heat resistance by holding it in an oven at 540-570°C temperature. After 10-20 hours of heating, the samples were taken out to study their microstructure and hardness. The tempering of hardening structures took place in 50-60 hours - i.e. increased wear resistance was not provided during long-term operation in the presence of superheated steam.

V. CONCLUSION

1. The comparative 200-300% increase in the wear resistance of GOST 40KhN2MFA steel after laser heat treatment in comparison with the base large diesel engines crankshafts metal allows us to recommend the developed laser heat treatment technology with minimal melting of the surfaces of these parts as a technology, valid for industrial introduction.
2. Over the course of the study, it has been established that the presence of a minimal (up to 0.1 mm of depth) melting of the middle part (5-6 mm wide) of the surface of the laser heat treatment tracks makes it possible to increase their depth to 1.0 mm with an8-9 mm total track width. To eliminate cracking of the hardened surface of the crankshaft samples of GOST 40KhN2MFA steel during operation, it is advisable to apply laser heat treatment tracks with a gap of 1-2 mm, and also to perform volumetric heat treatment of parts after laser heat treatment. Such heat treatment includes heating up to 220-250°C, holding for 3-4 hours and subsequent cooling in air.
3. It has been established that laser heat treatment of GOST 40KhN2MFA steel makes it possible to increase wear resistance only for machined parts that operate under relatively low (up to 200°C) temperatures. At the same time, the heat resistance of the steel under consideration does not increase, and subsequent heating of the detail to temperatures of 540–570°C completely eliminates the laser heat treatment effect.

REFERENCES

[1]. Enomoto, M., Li, S., Yang, Z. N., Zhang, C., & Yang, Z. G. [2018]. Partition and non-partition transition of austenite growth from a ferrite and cementite mixture in hypo-and hypereutectoid Fe-C-Mn alloys. Calphad, Vol.61, pp. 116-125.

[2]. Brezocnik, M., & Župerl, U. [2021]. Optimization of the continuous casting process of hypoeutectoid steel grades using multiple linear regression and genetic programming - An industrial study. Metals, Vol.11, Issue 6, pg. 972.

[3]. Smokvina Hanza, S., Marohnić, T., Iljkić, D., & Basan, R. [2021]. Artificial Neural Networks-Based Prediction of Hardness of Low-Alloy Steels Using Specific Jominy Distance. Metals, Vol.11, Issue 5, pg. 714.

[4]. Tyurin, Y. M., Kolisnichenko, O. V., Korzhyk, V. M., Gos, I. D., Ganushchak, O. V., Ying, J., & Fengping, Z. [2021]. Pulse-plasma modification of surface of steel hot drawing dies of titanium alloy products. The Paton Welding Journal, Vol.05, pg. 51-56.

[5]. Buitkenov, D., Rakhadilov, B. K., Tuyakbaev, B. T., Sagdoldina, Z. B., & Kenesbekov, A. B. [2019]. Structure and properties of detonation coatings based on titanium carbosilicide. Key Engineering Materials. Vol.821, pp. 301-306.

[6]. Klyui, N., Sliepkin, O., Tsabiy, L., Temchenko, V., Chorniy, V., & Zatovsky, I. [2019, September]. Gas detonation deposition technology–new prospectives for production of Ca-phosphate biocompatible coatings onto medical implants. In 2019 IEEE 9th International Conference Nanomaterials: Applications & Properties (NAP), id. 02BA04-1. IEEE.

[7]. Berdnikova, O. M., Tyurin, Y. M., Kolisnichenko, O. V., Kushnarova, O. S., Polovetskiy, Y. V., Titkov, E. P., & Yeremyeyeva, L. T. [2022]. Nanoscale structures of detonation-sprayed Metal–Ceramic coatings of the Ni–Cr–Fe–B–Si system. Nanosistemi, Nanomateriali, Nanotehnologii, Vol.20, Issue 1, pg. 97-109.

[8]. Taran, V. S., Garkusha, I. E., Tymoshenko, O. I., Taran, A. V., Misiruk, I. O., Skoblo, T. S., ... & Nikolaychukd, G. P. [2019]. Development of Niobium Based Coatings Prepared by Ion-Plasma Vacuum-Arc Deposition. Plasma Medicine, Vol.9, Issue 3, pp. 251-259.

[9]. Khaskin, V. Yu., Shelyagin, V. D., & Bernatsky, A. V. [2015]. Modern state and challenges for development of laser and hybrid surfacing technologies. The Paton Welding Journal, Vol.5-6, pp. 26-29.

[10]. Orazi, L., Fortunato, A., Cuccolini, G., & Tani, G. [2010]. An efficient model for laser surface hardening of hypo-eutectoid steels. Applied Surface Science, Vol.256, Issue 6, pg. 1913-1919.

[11]. Bernatskyi, A., & Khaskin, V. [2021]. The history of the creation of lasers and analysis of the impact of their application in the material processing on the development of certain industries. History of Science and Technology, Vol.11, Issue 1, pp. 125-149.

[12]. Radkiewicz, P., Laurentowski, M., & Reiner, J. [2022]. Improvement of laser hardening technology with oscillating beam using multiphysics simulation. Procedia CIRP, Vol.111, pp. 557-561.

[13]. Lesyk, D. A., Martinez, S., Mordyuk, B. N., Dzhemelinskyi, V. V., Lamikiz, A., Prokopenko, G. I., ... & Grinkevych, K. E. [2020]. Combining laser transformation hardening and ultrasonic impact strain hardening for enhanced wear resistance of AISI 1045 steel. Wear, Vol.462, id. 203494.

[14]. Shelyagin, V., Bernatskyi, A., Siora, O., Nabok, T., Shamsutdinova, N., & Sokolovskyi, M. [2021, August]. Historical Review of Technological CO 2 Lasers Development, Manufacturing and Operation Stages at EO Paton Electric Welding Institute of the NAS of Ukraine. In 2021 IEEE 3rd Ukraine Conference on Electrical and Computer Engineering (UKRCON), pp. 589-593. IEEE.

[15]. Lesyk, D., Hruška, M., Dzhemelinkyi, V., Danyleiko, O., Honner, M. [2022]. Selective Surface Modification of Complexly Shaped Steel Parts by Robot-Assisted 3D Scanning Laser Hardening System. In: Karabegović, I., Kovačević, A., Mandžuka, S. (eds) International Conference “New Technologies, Development and Applications V” (NT 2022). Lecture Notes in Networks and Systems, Vol.472, pp. 30-36. Springer, Cham.

[16]. Ormanova, M., Petrov, P., & Kovacheva, D. [2017]. Electron beam surface treatment of tool steels. Vacuum, Vol. 135, pp. 7-12.

[17]. Węglowski, M. S., Błacha, S., & Phillips, A. [2016]. Electron beam welding–techniques and trends–review. Vacuum, Vol.130, pp. 72-92.

[18]. Fu, Y., Hu, J., Shen, X., Wang, Y., & Zhao, W. [2017]. Surface hardening of 30CrMnSiA steel using continuous electron beam. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, Vol.410, pp. 207-214.

[19]. Rakhadilov, B. K., Buranich, V. V., Satbayeva, Z. A., Sagdoldina, Z. B., Kozhanova, R. S., & Pogrebnjak, A. D. [2020]. The cathodic electrolytic plasma hardening of the 20Cr2Ni4A chromium-nickel steel. Journal of Materials Research and Technology, Vol.9, Issue 4, id. 6969-6976.

[20]. Baizhan, D., Rakhadilov, B., Zhurerova, L., Tyurin, Y., Sagdoldina, Z., Adilkanova, M., & Kozhanova, R. [2022]. Investigation of Changes in the Structural-Phase State and the Efficiency of Hardening of 30CrMnSiA Steel by the Method of Electrolytic Plasma Thermocyclic Surface Treatment. Coatings, Vol.12, Issue 11, id. 1696.

[21]. Dashtbozorg, B., Penchev, P., Romano, J. M., Li, X., Sammons, R. L., Dimov, S., & Dong, H. [2021]. Development of surfaces with antibacterial durability through combined S phase plasma hardening and athermal femtosecond laser texturing. Applied Surface Science, Vol. 565, id. 150594.