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RESEARCH INTO THE INFLUENCE OF LASER SCANNING SPEED ON THE CHARACTERISTICS OF 10G2 STEEL

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Abstract

A study was carried out of the dependence of the characteristics of strength and ductility of structural steel 10G2 samples on the modes of laser surface hardening and alloying with a fiber laser. On the opposite planes of a sample with overall dimensions of 6×20×200mm, 5 tracks were applied. Samples were tested for static destruction. It was established that the destruction of the treated samples in all cases was of a viscous nature with a satisfactory level of destructive deformations at stresses above the strength limit of the original material. Tensile diagrams indicate an insignificant effect of laser treatment on the elastic modulus of the material. The results obtained can serve as a basis for studying the relationship between laser beam heating modes and the material properties of the strengthened zone.

Keywords: laser hardening, alloying, scanning speed, temporary resistance, relative elongation.

ИССЛЕДОВАНИЕ ВЛИЯНИЯ СКОРОСТИ ЛАЗЕРНОГО СКАНИРОВАНИЯ НА ХАРАКТЕРИСТИКИ СТАЛИ 10Г2

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Реферат

Проведено исследование зависимости характеристик прочности и пластичности образцов из конструкционной стали 10Г2 от режимов лазерной поверхностной закалки и легирования волоконным лазером. На противоположных плоскостях образца с габаритными размерами 6×20×200 мм наносились по 5 дорожек. Проведены испытания образцов на статическое разрушение. Установлено, что разрушение обработанных образцов во всех случаях имело вязкий характер с удовлетворительным уровнем разрушающих деформаций при напряжениях выше предела прочности исходного материала. Диаграммы растяжения указывают на незначительное влияние лазерной обработки на величину модуля упругости материала. Полученные результаты могут служить базой для исследования взаимосвязи между режимами нагрева лазерным лучом и свойствами материала упрочненной зоны.

Ключевые слова: лазерная закалка, легирование, скорость сканирования, временное сопротивление, относительное удлинение.

Introduction

Laser surface treatment technologies in some cases replace traditional heat treatment methods. This is determined by the advantages of a focused laser radiation: non-contact and localized thermal impacts, minimal heat-affected zone, high heating and cooling rates, reduced residual stress levels, minimized hogging, and increased structure dispersion [1]. Laser hardening can be considered as an alternative to surface hardening by carburization and subsequent volumetric hardening, as well as ion plasma nitriding. The scanning beam laser hardening technology without melting eliminates the need for surface grinding after hardening.

The relevance of problems associated with the influence of laser hardening modes on the structure and properties of various materials is confirmed by numerous publications of domestic and foreign scientists [1–17]. The authors of [1] were involved in determining the optimal laser hardening conditions for high-speed tool steel R6M5. As a result of testing samples processed using a technological gas CO2 laser at various powers and speeds of movement of a focused laser beam, it was found that laser hardening at a power of 600 W, a processing speed of 6 mm/s and a spot diameter of 3 mm increases the durability of knurling rollers up to 28 % compared to traditional volumetric heat treatment. Studies of the influence of laser pulse hardening on the structure, phase composition of tungsten-cobalt hard alloys VK6 and VK8 and the performance characteristics of cutting tools made on their basis were carried out in [2]. As a result of the research, optimal laser hardening modes were established, under which the durability of the hardened tool increases by 1.5-2.0 times. Research [3] is devoted to the effect of laser surface hardening on changes in the microstructure and wear resistance of tool die steel AISI H11 (analogous to 4X5МФС). Laser hardening was carried out using a TruFiber 400 fiber laser with a scanning optical head. As a result of comparing the wear trace profiles of AISI H11 tool steel, it was found that laser hardening of the surface is characterized by a minimum penetration depth and maximum roughness. When measuring microhardness in the direction perpendicular to the laser beam tracks, the authors noted local softening due to the overlap of adjacent laser tracks. Article [4] investigated the influence of laser radiation parameters on the structure, microhardness and surface quality of 4Kh5MFS steel during laser hardening. It has been shown that laser hardening of 4Kh5MFS steel makes it possible to obtain a surface hard-ness of the order of 675–750 HV and a roughness of the order of 0.6–1.2 microns. In article [5], the microstructure, wear resistance (dry sliding fric-tion) and microhardness of steels AISI 1018 (analogous to steel 15), AISI 4140 (analogous to 42HFA) and gray cast iron after hardening with a diode laser with a power of 4 kW at three scanning speeds of 1000, 1500 and 2000 were studied. mm/min. As a result of processing, the hardness of AISI 1018 and 4140 steels increased from an average base value of 230 to 349 and 639 HV, respectively, and the hardness of gray cast iron from 330 HV to 830 HV. In article [6], the authors compared the hardness, depth of the hardened layer and wear resistance of the piston head of a diesel engine after laser hardening with a CO_2 laser and during high-frequency hardening. An increase in the hardness and depth of the hardened layer was noted during laser hardening in comparison with high-frequency hardening.

As a result of wear tests, it was found that the wear resistance of laser-hardened samples is 1.3 times higher than that of samples subjected to high-frequency hardening. In article [9], the authors studied the influence of various laser processing modes on the structure and properties of 20Kh3N3MFBA steel after volumetric heat treatment and the possibility of replacing the carburizing process with laser hardening. It has been established that the depth of the hardened layer depends on the speed of movement of the laser beam: the lower the speed, the greater the depth of the hardened layer. An optimal hardening mode has been established (speed 7 mm/s), at which maximum micro-hardness on the surface is achieved. It was determined in [11] that for structural steel 30KhGSA, hardening by continuous radiation of a multichannel (48 beams) CO2 laser on a complex model TsLT-Yu-5 with surface melting to a depth of 0.5 mm is optimal laser hardening mode. In this laser hardening mode, the processing zone consists mainly of tempered martensite, which provides high micro-hardness and abrasive wear resistance of the steel. The authors of work [12] were engaged in optimizing the degree of overlap of the hardened zone, and the authors of work [13] determined the optimal gap (2 mm) between two successive passes of a laser beam for processing steels S-45 (steel 45) and S-30 (Steel 30). In article [17], studies were carried out on the dependence of the characteristics of strength and ductility, as well as the microhardness of samples made of corrosion-resistant steel 40Cr13 on the modes of laser surface hardening with a fiber laser. It was established that the destruction of the treated samples in all cases was of a brittle nature with a low level of destructive deformations at stresses below the tensile strength of the original material.

It should be noted that research mainly consists of determining the influence of laser hardening modes on wear resistance, and the problem of the influence of laser processing on the strength characteristics and plasticity characteristics of the material is paid insufficient attention. The analysis of reference sources showed that among numerous publications of domestic and foreign scientists, there is insufficient research on the relationship between laser beam heating modes and the material mechanical properties of the strengthened zone.

1. Equipment and methods of conducting testing

The samples were made of 10G2 structural steel. Sample dimensions: thickness – 6 mm, width – 20 mm and length – 200 mm (deviations from the specified dimensions are taken into account when processing the results).

The samples were subjected to laser surface treatment using the radiation of a 1 kW ytterbium fiber laser with a lens for focusing the laser radiation, a moving system, and a head scanning the laser beam [10] under various processing modes (Table 1). Three samples were used for each quenching and alloying mode. On the opposite planes of a sample with overall dimensions of 20x200 mm, 5 tracks were applied. The length of the laser tracks was 170 mm. Each track was processed from the same side (Figure 1). The laser spot size is 0.35 mm. The distance from the sample surface to the last deflector was 450 mm. For alloying, a mixture of amorphous boron with acetone and BF-4 glue was previously applied to the samples.

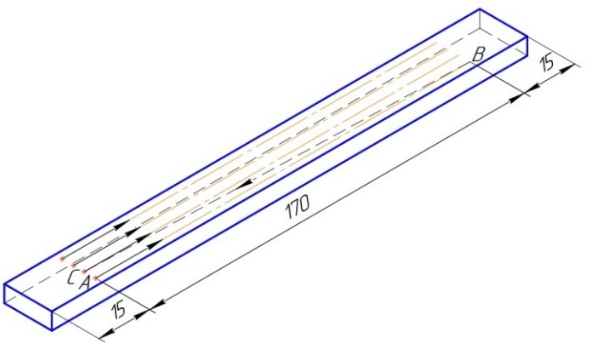


Figure 1 – Diagram of the movement of the laser scanning spot along the surface of the sample

To determine the strength characteristics, the samples were tested for static tension in accordance with GOST 1497-84 "Metals. Tensile test methods" on a Meitesi WDW-300 tensile testing machine (China). Tensile tests of the samples were carried out under load at a speed of 5 mm/min.

Table 1 – Laser processing modes

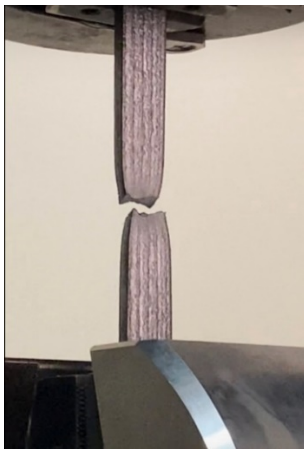
Type of processing	Scanning spot, mm	Number of lines, pcs	Scanning frequency, Hz	Scanning speed *V*, mm/min	Sample number
Hardening	4 × 2,25	7	220	300	1a, 1b, 1c
				500	2a, 2b, 2c
				700	3a, 3b, 3c
Alloying				300	4a, 4b, 4c
				500	5a, 5b, 5c
				700	6a, 6b, 6c

***Note**: in the column "Sample number" 1, 2, 3, 4, 5, 6 – batch number; a, b, c – sample number in the batch.*

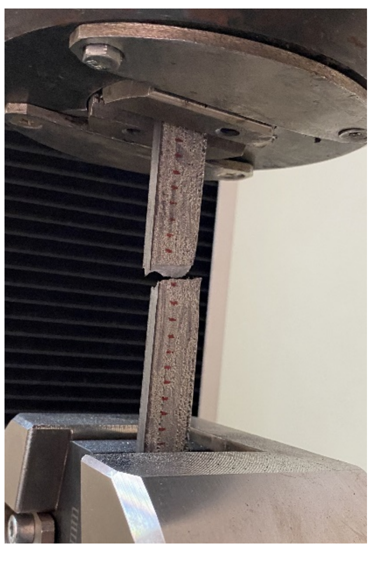
2. Some results and their consideration. The destruction of untreated (UT) and treated samples occurred within the calculated length with the formation of a "neck", a decrease in the cross-sectional area in the fracture zone and an increase in the length of the sample. All hardened and alloyed samples destroyed along sections perpendicular to the direction of the tensile load, and the samples, not subject to laser treatment, destroyed along sections located at an angle to the direction of the tensile force (Figure 2).

Examples of the destroyed samples and fracture sections are shown in Figure 3. All samples exhibit significant cold-hardening of the surface layers.

a – untreated sample



b – laser-hardened sample



c – laser-alloyed sample

Figure 2 – Tensile testing of material samples

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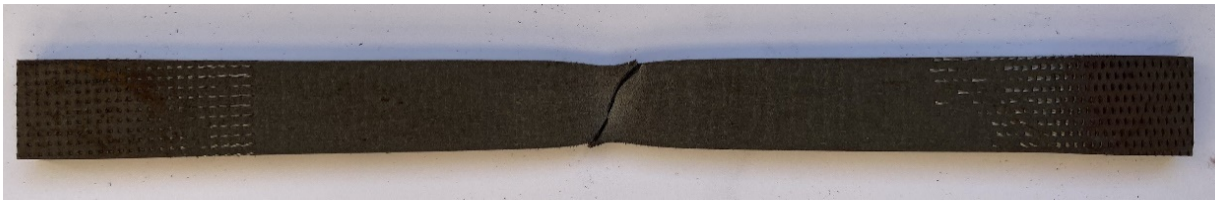
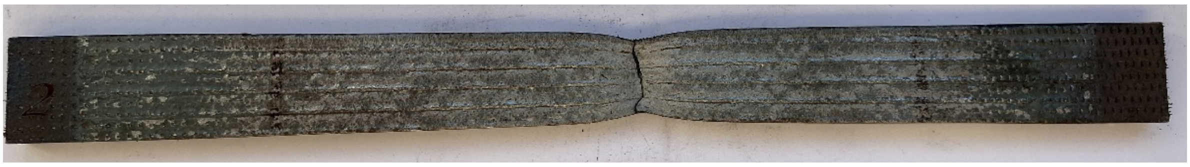


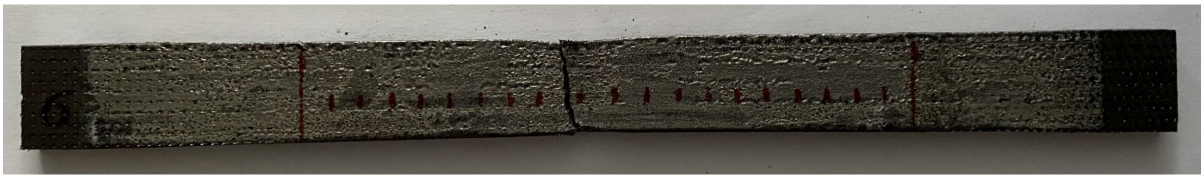
a – destroyed samples (sample HO2)

b – destruction cross-section (sample HO2)



c – destroyed samples (sample 1b)

d – destruction cross-section (sample 1b)



e – destroyed samples (sample 6a)

f – destruction cross-section (sample 6a)

Figure 3 – Destroyed samples (*a, c, e*) and destruction cross-section (*b, d, f*)

Based on the test results, the temporal resistance and relative elongation of all samples were determined. The data is summarized in table 2.

Table 2 – Some characteristics when testing flat samples

Scanning spot, speed of longitudinal movement	Type of processing	Batch number	Marking	Temporal strength, $\sigma_в$, MPa	Relative elongation, δ, %
	Untreated samples	HO	1	567	26
			2	567	31
			3	565	31
4 × 2,25 mm (7 lines) 300 mm/min	Hardening	1	a	648	17
			b	625	19
			c	666	19
4 × 2,25 mm (7 lines) 500 mm/min	Hardening	2	a	622	22
			b	628	23
			c	628	18
4 × 2,25 mm (7 lines) 700 mm/min	Hardening	3	a	626	21
			b	628	20
			c	622	23
4 × 2,25 mm (7 lines) 300 mm/min	Alloying	4	a	622	14
			b	624	12
			c	625	14
4 × 2,25 mm (7 lines) 500 mm/min	Alloying	5	a	635	13
			b	667	15
			c	626	9
4 × 2,25 mm (7 lines) 700 mm/min	Alloying	6	a	651	15
			b	644	14
			c	643	15

Based on the results of the tests, the dependences of the σ stresses which arise in the samples on the ε deformations were plotted (Figure 4). For ease of comparison, the graphs were superimposed on the graphs of the samples that were not subjected to laser treatment.

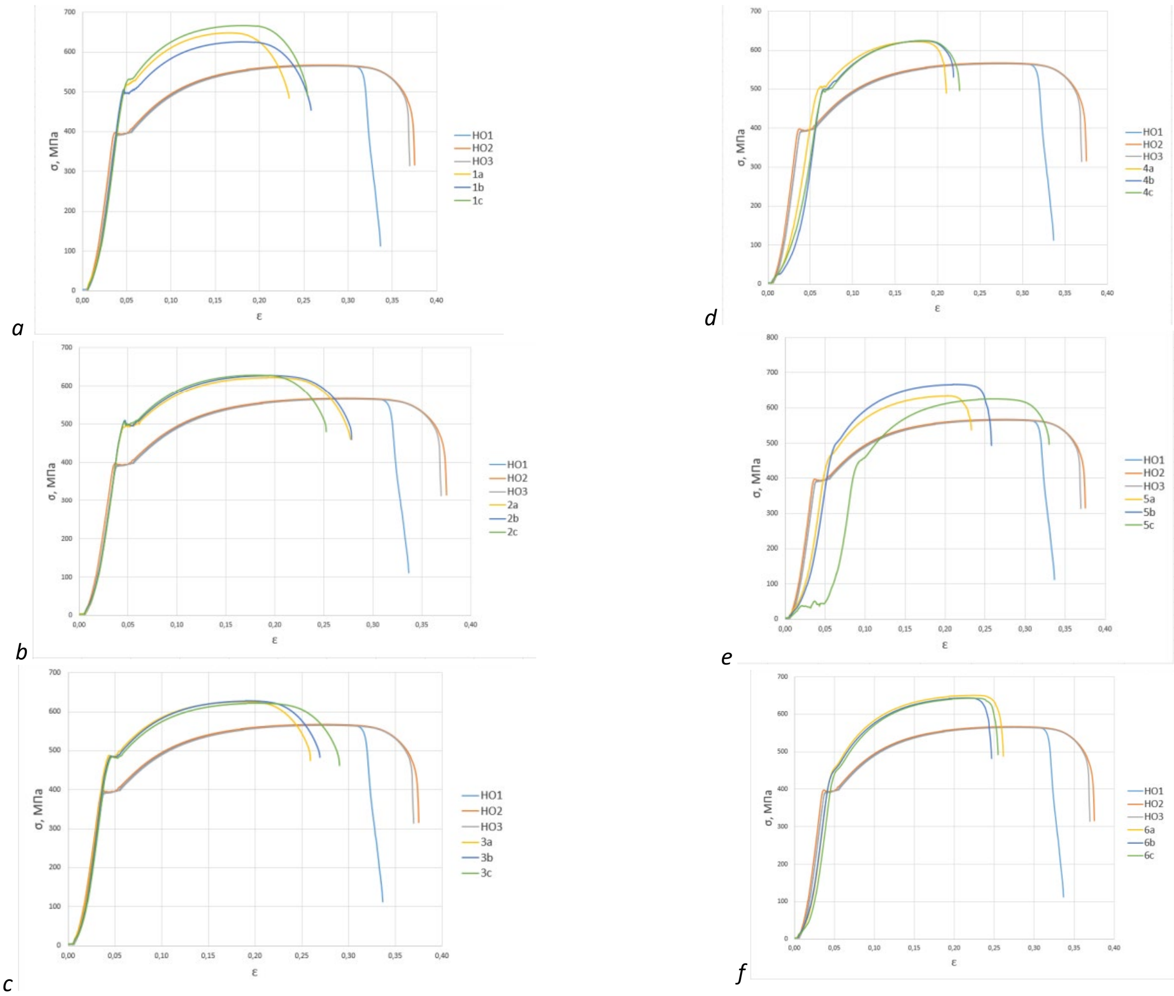


Figure 4 – Dependence of stresses (σ) arising in samples of 10G2 steel on deformations (ε):
a – batch No. 1, *b* – batch No. 2, *c* – batch No. 3; *d* – batch No. 4; *e* – batch No. 5, *f* – batch No. 6

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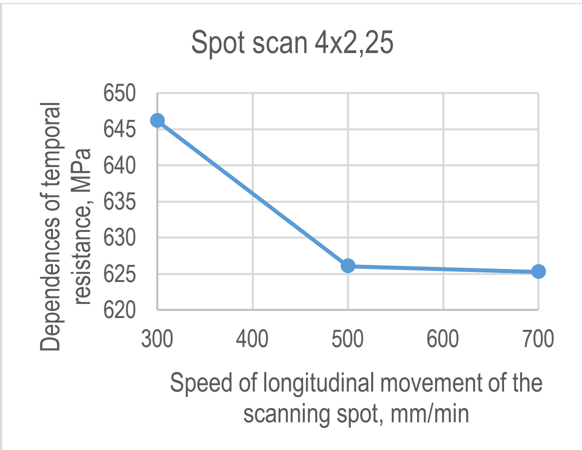
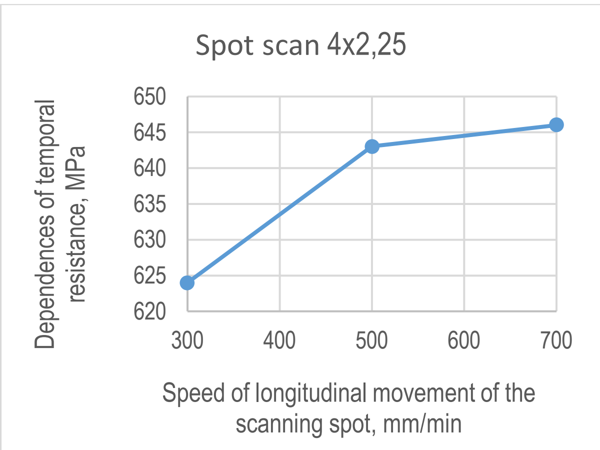
The analysis of the tensile diagrams indicates an insignificant influence of scanning speed parameters on the elastic modulus of the material in the studied range of parameters. While with laser alloying, the strain diagrams indicate a more significant influence of the laser scanning speed on the elastic modulus of the material. The destruction of hardened and alloyed samples occurred with a slight decrease in the level of destructive deformations. The test results show a high degree of repeatability of the obtained σ (ε) dependences.

The results show that the maximum stress for all the samples subjected to hardening and alloying increased in comparison with the untreated samples: by 14 % for batches No. 1, No. 6; by 13 % for batch No. 5; by 10 %; for batches No. 2, No. 3, No. 4. It should be noted that there is a slight decrease in the plasticity characteristics of 10G2 steel during laser hardening: a relative elongation of the hardened samples does not exceed 17–23 %, with a similar parameter of 31 % for the original samples. Whereas with laser alloying, the ductility characteristics decreased by more than half: relative elongation of the alloyed samples constituted 6–15 %. The decrease in plasticity characteristics is connected with a significant increase in the hardness of the quenched and alloyed zone and presence of microcracks on its surface.

Based on the test results, the dependences of the batch-average temporary resistance (Figure *5 a*, *b*) and relative elongation (Figure *6 a, b*) of hardened samples on the speed of the scanning spot longitudinal movement were determined.

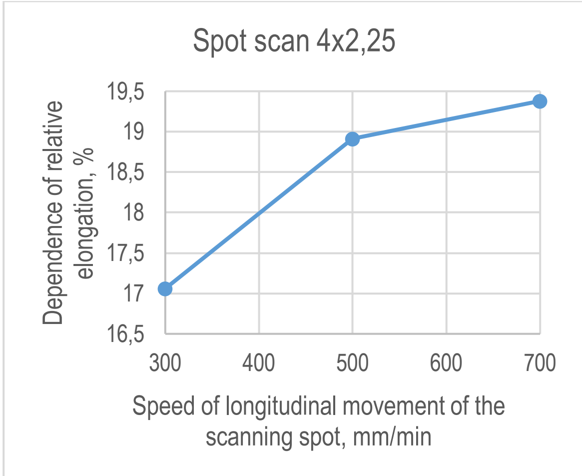


a

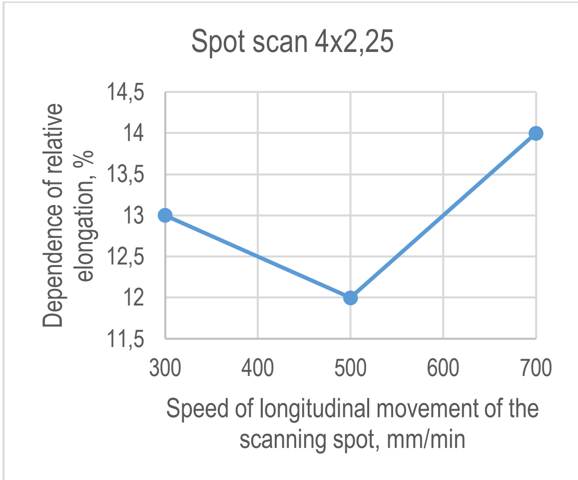


b

Figure 5 – Dependences of temporal resistance $\sigma_в$ on the speed of longitudinal movement of the scanning spot:
a – hardened samples; *b* – alloyed samples



a



b

Figure 6 – Dependence of relative elongation δ on the speed of longitudinal movement of the scanning spot:
a – hardened samples; *b* – alloyed samples

It has been determined that during laser hardening, the maximum value of temporal resistance corresponds to the lowest scanning speed (300 mm/min). With laser alloying, the highest value of temporal resistance corresponds to the maximum scanning speed (700 mm/min).

Conclusion. The research into the influence of laser scanning speed during laser hardening by radiation from a 1 kW ytterbium fiber laser on the mechanical characteristics of the 10G2 steel samples has been carried out. The studies were conducted at speeds of 300, 500, 700 mm/min. The results of static tensile tests point to a ductile nature of destruction of the treated samples. The destruction stresses of the hardened samples increased by 10–14 % with a proportional decrease in ductility characteristics. The destruction stresses of the alloyed samples also increased by 10–14 % with a decrease in plasticity characteristics by more than two times. The tensile diagrams showed an insignificant change in the elasticity modulus of the sample material after laser hardening and a more significant one during laser alloying compared to the original material.

The research results can be used to establish a relationship between a laser hardening modes and properties of the hardened zone material.

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