Study of laser cutting of low-alloy steel with using various gases

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Abstract. Based on the laser cutting of steel 09G2S, specific features of the power tool and its use are shown. The basic requirements for the quality of the cut surface and a wide range of material properties arising from the characteristics of the energy tool are formulated. The formation of a heat-affected zone, its structure and properties, the formation of macro- and microgeometry of the cut depending on the used working gas are described. The influence of laser cutting parameters on the provision of the required quality and properties of steel is considered.

1. Introduction
In engineering industries, a new energy-intensive technologies, such as electron-beam, plasma, laser, hydraulic and water-jet processing, are becoming more widespread [1-6]. These technologies are fundamentally different from traditional ones. Their main difference is in the energy tool with a high-power energy flow, which the material treated without directly touching the surface and with significantly increased productivity, as well as in obtaining new properties in the treated material.

One of the most common energy-intensive technologies used in machine-building plants is cutting materials. It refers to the flexible technologies and is used in the production of not only blanks, but also as the final operation of manufacturing parts. As an energy tool for cutting, the laser radiation is used, which causes, depending on the power density supplied to the cutting zone, local melting, oxidation and evaporation of the material instead of the traditional chip removal. The laser cutting used in the blank areas may exclude further machining of the blanks. The replacement of the laser cutting milling or cutting parts by stamping significantly increases the economic efficiency of processing. The features of the using the laser for cutting materials are considered [7-8].

In contrast to mechanical cutting, when thermal action of a laser, structural changes occur in the cut zone, leading to a change in the mechanical properties of the material. The latter, along with macro- and microgeometric properties of the cut surface, is an important factor determining the place of laser treatment in the technological process of manufacturing machine parts and the quality of processing. The latter, along with macro- and microgeometric properties of the cut surface, is an important factor determining the place of laser treatment in the technological process of manufacturing machine parts and the quality of processing.

The purpose of this work is to study the features of the formation of the cutting edge when exposed to laser radiation using different gases.
2. Experimental studies

The choice of working gas largely depends on the material to be cut. The treatment of low-alloyed steel, as a rule, is performed in an oxygen environment. Oxygen supplied under pressure to the zone of impact of the beam provokes a powerful exothermic reaction, so that relatively thick sheets of metal can be cut. When cutting with oxygen, the heat-affected zone with a modified structure has a considerable thickness, and scale is also present, which is undesirable in some cases. Air, nitrogen and carbon dioxide were used as working gas.

Low-alloy steel 09G2S widely spread in the industry served as the research material. The blanks were in the form of strip blanks with a thickness of 3 mm.

The cutting was performed using a LS-2 serial laser unit with a power of 2 kW manufactured by IRE-Polus with an IPG d38 f100W-150-200 optical head with a focal length of 150mm. The cutting metal samples conducted by setting the focal plane on the surface of the workpiece. The tool speed varied from 5 to 30 mm/s.

After cutting, the structure of the cut surface, its geometry were studied and the roughness in accordance with GOST 2309-73; 2789-73 was determined. The height parameter Ra is selected as a quantitative indicator of the degree of roughness.

Cut surfaces were photographed with a digital camera and microscope with magnifications from 50 to 200.

A characteristic feature of the heat-affected zone is the presence of burr - residues of molten metal, crystallized on the lower (base) surface of the workpiece. The burr worsens the quality of the laser cut and makes the operation of its removal necessary.

The specific features of the work of the energy tool - a huge energy density, concentrated in a small area of the material - leads to high rates of heating and cooling of this area (up to 106 K / s). This increases the possibility of diffusionless mechanisms of transformations, there is a sharp structural and chemical heterogeneity occurs, the effect of structural heredity is clearly manifested.

Modes of laser cutting of steel 09G2S are presented in table 1.

| Mode | Working gas       | Gas pressure p, atm | Laser radiation speed v, mm / s | Laser power N, W |
|------|-------------------|---------------------|---------------------------------|------------------|
| 1    | Air               | 7                   | 30                              | 1300             |
| 2    | Air               | 7                   | 22                              | 1000             |
| 3    | Carbon Dioxide    | 13                  | 22                              | 1100             |
| 4    | Carbon Dioxide    | 13                  | 18                              | 1000             |
| 5    | Carbon Dioxide    | 13                  | 30                              | 1300             |
| 6    | Nitrogen          | 13                  | 30                              | 1300             |
| 7    | Nitrogen          | 13                  | 20                              | 1000             |
| 8    | Nitrogen          | 13                  | 22                              | 1100             |

The width of the heat-affected zone depends on the type of working gas and the treatment mode. For the studied samples, from the air was obtained the largest width. In all samples, the heat-affected zone expands with approaching the bottom surface of the workpiece. The cutting speed has a significant effect on the size of the heat affected zone - the width of the zone decreases with increasing speed (Figure 1). Table 2 shows the quality parameters of the cutting surface and dimensions.
Figure 1. Surfaces of laser cutting of steel 09G2S (from left to right): the cutting edge, top view, in section × 50; a) mode 2; b) mode 4; c) mode 7

The surface of the laser cut is characterized by a certain microgeometry, which is represented by a set of periodically repeated irregularities (waviness, striation, roughness) described by a set of parameters characterizing the average and maximum height of the irregularities, their width, and the distance between them. The view of the cut surfaces under various laser cutting conditions is shown in Figure 1; it allows to identify the following characteristics. According to the depth of cut, at least three striations can be distinguished. The first zone is located closer to the upper side of the workpiece. The grooves are elongated in the direction of laser radiation in this zone. The second zone differs from the first by changing the direction of the grooves elongation (distortion, or the so-called lag of the cutting line). The third zone, located at a short distance from the lower surface of the workpiece, is characterized by a significant change in the size and nature of roughness. On the lower surface of the workpiece during gas laser cutting there is sticking of burrs.
Table 2. The quality parameters of cut

| Sample No | Roughness Ra, µm | Burr l, mm | Heat-affected N, mm | Cut width b, mm |
|-----------|------------------|------------|--------------------|-----------------|
| 1         | 1,086            | 0,70       | 0,20               | 0,30            |
| 2         | 0,913            | 0,49       | 0,38               | 0,29            |
| 3         | 2,005            | 0,55       | 0,05               | 0,29            |
| 4         | 2,521            | 0,43       | 0,05               | 0,27            |
| 5         | 2,045            | 0,33       | 0,03               | 0,25            |
| 6         | 1,064            | 0,46       | 0,01               | 0,25            |
| 7         | 1,449            | 0,48       | 0,01               | 0,15            |
| 8         | 1,132            | 0,46       | 0,01               | 0,19            |

3. Conclusion
The influence of laser cutting on the properties of materials in the heat-affected zone determines the possibility of using an energy tool in the technological scheme of products production. If the material properties in the laser cutting zone do not reduce the functional properties required from the product, laser cutting can be used as the final technological operation. In other cases, it is used for the manufacture of semi-finished products and precedes other technological operations (in particular, machining). According to the purpose of laser cutting, requirements for the quality of the cut surface can vary considerably. Working gases can be used different to reduce the heat-affected zone.

References
[1] Grigoryants A G, Shiganov I N and Misyurov A I 2006 Processes of laser processing Moscow publishing house MGTU im. N. Uh. Bauman, 664 p
[2] Zvezdin V V, Hisamutdinov R M, Rakhimov R R, Israfilov I H and Saubanov R R 2018 Technology of overlay laser welding of durable powdery into blade edge of miller IOP Conference Series: Materials Science and Engineering Volume 412, Issue 1 Article number 012083
[3] Zvezdin V V, Rakhimov R R, Saubanov R R, Israfilov I H and Akhtiamov R F 2017 Management of laser welding based on analysis informative signals IOP Conference Series: Materials Science and Engineering Volume 240, Issue 1 Article number 012073
[4] Gabdrakhmanov A T, Galiakbarov A T, Samigullin A D and Galiakbarov R T 2016 The calculation of a thermal field in the surface of a processed partunder the influence of a low-temperature plasma IOP Conf. Ser.: Mater. Sci. Eng., Volume 134, Issue 1, Article number 012040
[5] Gabdrakhmanov A T, Israphilov I H, Galiakbarov A T and Samigullin A D 2016 Improving the efficiency of plasma heat treatment of metals Journal of Physics: Conference Series Volume 669, Article number 012014
[6] Gabdrakhmanov A T, Israphilov I H and Galiakbarov A T 2014 The study the erosion of the electrodes under the influence moving electric arc Journal of Physics: Conference Series Volume 567, Issue 1, Article number 012013
[7] Gabdrakhmanov A T, Shafigullin LN, Galimov E R and Ibragimov A R 2017 Surface thermohardening by the fast-moving electric arch IOP Conf. Series: Journal of Physics: Conf. Series. Volume 789 Article number 012010
[8] Denisov D G, Kashapov N F and Kashapov R N 2015 The appearance of shock waves in the plasma electrolytic processing Iop conference series: materials science and engineering №012005