SURFACE HARDENING OF STEELS BY ALLOYING WITH LASER HEATING AND SUBSEQUENT CHEMICAL HEAT TREATMENT

O. V. Chudina and T. M. Borovskaya


The necessity of providing a high set of operating properties has stimulated the development of combined technologies of surface hardening. A combination of laser alloying of low-carbon steels by nitride-forming elements (V, Cr, Mo, Al) with subsequent chemical heat treatment seems promising in this respect. Such a combined treatment provides a favorable distribution of residual stresses, elevates considerably the microhardness of the strengthened layers, and increases the wear resistance by a factor of 1.5 - 3 compared to nitrided nitralloys like steel 38Kh2MYuA.

Laser technologies are becoming an acknowledged means of surface hardening. This method has the advantage of being highly adaptable to manufacture, makes it possible to treat local volumes of the parts in places of intense wear, can provide a regular surface relief of a Charpy type with a high wear resistance, causes inconsiderable deformations of the processed parts due to the locality of the heat treatment, and provides a specified set of physical and mechanical properties of the processed parts by alloying them with different elements with laser heating. Laser heating can also improve such properties of metals and alloys as the corrosion, wear, and heat resistances. However, the use of laser chemical heat treatment (LCHT) is hampered by the negative effect on the operating properties of the parts due to the high difference in the internal stresses on the boundary separating the zone of laser effect (ZLE) and the matrix. In order to diminish the stress drop, the parts are heated, but this decreases their hardness and makes the laser treatment less effective.

It becomes obvious that LCHT cannot be the final state of the manufacturing process and a combined technology is required for surface strengthening of steels. In particular, a combination of laser alloying (LCHT) with subsequent conventional chemical heat treatment (nitriding, nitrocarburizing, etc.) can be a promising variant. Such a combined treatment not only decreases the differences in the internal stresses but also improves substantially the physical and mechanical properties of the hardened layers.

A detailed study of the effect of the parameters of laser radiation on the structure and properties of alloyed zones with determination of the conditions of the formation of zones with a uniform distribution of the alloying elements in them has been conducted in [1]. Optimum regimes of surface hardening with the use of laser heating are described in [2, 3].

The aim of the present work consists in developing a technology of surface hardening of steel by alloying it with laser heating and subsequent chemical heat treatment aimed at obtaining layers with a high set of physical and mechanical properties.

We studied low- and medium-carbon steels of grades 20, 40, 45, 20Kh, and 40K. Laser alloying was conducted using powders of nitride-forming elements such as V, Cr, Mo, and Al, i.e., elements that are contained in nitralloys (traditionally nitrided steels).

When the surface of the steel is treated by laser radiation in a continuous regime with a maximum power of 1 kW, the simplest process parameter for measuring the power density is the speed of motion of the laser beam. For a range of 10 - 20 mm/sec in the zone of LCHT the concentration of all the alloying elements is maximum.

A metallographic analysis with a high magnification has shown that as a result of laser alloying in a pulse regime the formed structure has a weakly pickling martensite type, whereas in a continuous radiation regime the structure is superfine-grained. Near the interface of the zone of laser effect and the matrix, the structure is columnar and oriented towards the maximum heat removal.

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A local microscopic x-ray spectral analysis has shown that the alloying elements in the ZLE under the chosen process regimes are distributed quite uniformly. Their concentrations (mass fractions) fluctuate (depending on the kind of alloying element) from 2 to 5% after a pulse laser treatment and from 5 to 17% after a continuous treatment. It has been estab-
lished that the region adjoining the interface of the molten zone and the matrix is depleted of the alloying elements.

A phase x-ray analysis has shown that a solid solution of substitution of the alloying elements in an α-phase is formed in the ZLE. In the case of molybdenum, the ZLE contains FeMo and Fe₂Mo₆ intermetallic phases.

The microhardness in the ZLE is distributed uniformly and corresponds to 500 – 800 H and 300 – 1200 H for pulse and continuous treatment regimes respectively. Under the molten zone we established a marked increase in the microhardness in the zone of thermal effect (ZTE), which is connected with the formation of high-carbon martensite due to the diffusion of carbon into this zone both from the matrix and from the melting zone. This effect is highest in the case where the steel is alloyed with V and Al.

High heating and cooling rates and phase transformations that occur in LCHT cause the formation of internal residual stresses in the surface layer. Great differences in the internal stresses that fluctuate from considerable compressive stresses in the center of the ZLE to considerable tensile stresses on the ZLE-matrix interface negatively affect the operating properties of the parts.

In chemical heat treatment of laser-alloyed steels, the stress drops in the center and on the ZLE-matrix interface decrease. In addition, in CHT of parts with a preliminarily formed relief of the LCHT zones, the total strengthening of the surface occurs with a considerable increase in the hardness of the ZLE due to the formation of special nitrides and carbides of the alloying elements. This makes it possible to create composite coatings with a high set of operating properties by using the combined technology.

We conducted chemical heat treatment of laser-alloyed specimens by a standard regime (nitriding at 570°C for 3 h, nitrocarburizing at 860°C for 6 h).

In the absence of alloyed zones, a nitride zone 15 – 20 μm thick is formed on the surface of the nitried layer; then follows a diffusion sublayer (the zone of internal nitriding). In nitriding of specimens alloyed with V and Cr, a thin (2 – 5 μm) nitride film is formed on the surface. The nitried layer is pickled off nonuniformly; in the center of the ZLE its thickness is minimum, and approaching the ZLE-matrix interface it increases gradually. As the nitriding time is increased, the nonuniformity of the layer diminishes and the front of the nitried layer is leveled. In nitriding of specimens alloyed with Mo and Al, the surface is covered with a nitride film that has a thickness virtually equal to that of the nitride film on a nonalloyed surface. The front of the nitried layer is leveled in a shorter saturation time.

The formation of the strengthened layer inside the zone of LCHT depends on the alloying element, in particular, on its effect on the dissolution of nitrogen in the iron. For example, we established a relationship between the phase composition of the ZLE and the microhardness. The high microhardness (1600 – 1800 H) in the ZLE of specimens alloyed with V and Cr is caused by the segregation of disperse special nitrides Cr₂N, VN, and V₃N in the nitriding process. In the ZLE of specimens alloyed with Al, nitriding results in a structure consisting of alloyed α- and γ'-phases with a high microhardness (about 2000 H), which is caused by the substantial difference in the specific volumes of these phases and the appearance of molybdenum-alloyed nitride phases based on iron. In this case the microhardness is not high (about 1100 H). In nitrocarburizing, the microhardness in the ZLE of specimens preliminarily alloyed with V and Al amounts to about 500 H and that of specimens alloyed with Cr and Mo is 1500 – 1900 H due to the segregation of disperse carbonitrides of the alloying elements.

The results of our study show that annealing of specimens from steel 20 laser-alloyed preliminarily with V, Mo, Cr, and Al decreases the microhardness. The part of the curve at which the microhardness remains virtually the same is attained after annealing at 250°C (Fig. 1a). In the case of a combined treatment (laser alloying of the surface + nitriding), the microhardness of the surface layer in the subsequent heating (annealing) depends considerably on the alloying element. It can be seen from Fig. 1b that the wear resistance of strengthened zones can be increased to 600°C by a combined treatment if the alloying elements in LCHT are V, Cr, and Mo. This can promote an increase in the wear resistance of parts operating under the conditions of sliding friction at an elevated temperature.

When studying the stress state of a surface strengthened by a combined treatment, we established the positive role of CHT in the distribution of internal stresses. In the nitriding process, the surface of the ZLE is subjected to a double action. On one hand, it is saturated with nitrogen, which causes...