"USE OF THE HYBRID LASER-ARC OR LASER-LIGHT WELDING INSTEAD OF LASER ONE ALLOWS TO INCREASE THE MELTING EFFICIENCY AND TO PROVIDE STABILITY OF WELD FORMATION AT WELDING METALS OF SMALL THICKNESS"

Ravi Vishwakarma[1], Prof.Pushpendra Kumar Sharma[2], Prof. Sachin Jain[3]

[1]*Post Graduate Student, NIIST, Bhopal*

[2]*Head Mechanical Engineering Department, NIIST, Bhopal*

[3]*Asst. Professor, NIIST, Bhopal*

ABSTRACT

Manufacturing economy to a large extent is based on fabrication cost & its strength of efficiency of welding. Welding Technology is one of the measures of industrial & thus global value of any country. Our present work is about hybrid-laser welding & spot welding in structural & machine parts construction using steels. Hybrid Laser Welding is a technique that combines a laser and electrical Arc Welding. In order to investigate, the behavior of this welding process, specimens were carried out with different parameters. Three-Four Tests destructive and not destructive, were made and hence to gain knowledge about the relations between joint geometry and welding properties. Furthermore, hybrid welding joints in order to understand the mechanical properties .some new advantages of hybrid laser welding. The model of combined action of laser beam and additional heat source, such as electric arc, plasma jet or high power arc lamp radiation has been developed. The laser beam - arc plasma interaction as well as peculiarity of hybrid thermo cycles influence on material microstructure are discussed to determine a design of technological equipment.

Keyword: *Hybrid welding, marten site, laser-light welding, microstructure, hybrid thermo cycles influence.*

1.1Introduction

There is a tendency of modern industry to decrease of constructions weight that is connected to necessity of increase of fuel efficiency during constant increase of oil cost. For this purpose new high-strength two- and three-phase steels are applied, their properties are defined by parameters of ensembles of nano-dimension inclusions. In particular, modern technologies of car bodies are based on use «tailored blanks» - the welded blanks subjected next punching. Weight decrease without strength decreasing is achieved by using high-strength biphase steels in the blanks production instead of low-carbon ones; however there is a problem to provide of necessary plasticity of welded seams. For the problem to be solved, a welding technology is necessary, which provides sufficient metal plasticity of the welded seams and welding quality, not yielding to quality of the laser welding used now. The use of high-speed heat cycling is most perspective to obtain set microstructure and mechanical properties [1]. It can be achieved in using for welding two heat sources following one after another, for example, tandem laser welding [2]. But from the economic point of view it is expedient to use cheap local sources of heating as the second source, such as an electric arc or a powerful lamp. The choice of the processing mode providing set microstructure and metal properties demands detailed understanding of phase and structural transformations processes in the material. Modern concepts about phase transformations mechanisms at laser action on steels [3], which formed on the basis of phase transitions thermodynamics, do not allow taking into account shifts of transformations points depending on heating and cooling rate, mutual influence of processes of a new phase growth and non-stationary diffusion, an initial state of the material. The quantitative description of microstructures is impossible without considering these factors and can be formulated only on the basis of the kinetic theory of phase transformations in steels [4]. For this purpose the exact calculation of a thermal cycle is necessary for the hybrid welding that is initial parameter for processes of phase transformations. Thus, it is necessary to pass consecutive steps of development of physical and mathematical models of welding processes, development of a material microstructure formation model in a processing zone, creation of the experimental stand and experimental researches of welding process. The present work also is devoted to the description of the solution of this complex problem. Interaction of pulse laser radiation with hybrid discharge plasma Spatial distribution of the additional heating source at hybrid influence on a material is one of determining factors for estimating its influence on metal microstructure formation. If intensity distribution of a "lamp" heat source at laser-light action depends only on characteristics of the light radiator, then the factor of the electric arc concentration at laser-arc action is determined by processes in a plasma plum of the hybrid discharge, arising above a work piece surface. As against laser welding when plasma formation results only in absorption and refraction of laser radiation when it passes through the plum [5], at laser-arc welding the plasma plum is an area determining mutual influence of laser and arc heating sources which presence explains [6] increase of heating efficiency for metal at combined action of the laser beam and electric arc. Structure and properties of the plasma plum in this case depend not only on laser radiation parameters [7], combination and consumption of protective gas [8], but also on the electric arc parameters. To describe processes in plasma of hybrid discharge at laser-arc welding with deep penetration in approximation of axially-symmetrical boundary layer there has been solved a problem about run-out of a hot metal vapor jet into the cold shielding gas in view of compressibility of a gas mix and volumetric heat generation due to laser radiation absorption in plasma. The plasma ionicity has been determined from the solution of a kinetic problem in approximation of constant collision frequencies for the helium - iron mix without assuming local thermal balance. To confirm the obtained results a series of experiments on the plasma plum interferometry has been carried out at pulse laser action on metal targets. The created mathematical model has allowed calculating dependence of plasma conductivity (fig. 1) on its composition, and distribution of the metal vapor concentration in the mix with shielding and environmental gases at hybrid laser-arc welding. Spatial distribution of the hybrid laser-arc heat source has been calculated too.

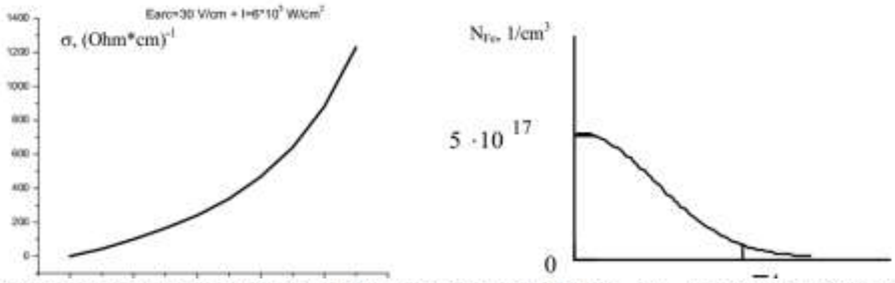


Fig.1. a) - Dependence of plasma conductivity on its chemical combination, b) - An example of calculation of spatial distribution of iron vapor concentration in helium at 1 cm above the target surface at laser-arc welding.

Model of a welding bath and processing zone at hybrid influence the mathematical model of the welding bath at the hybrid welding, allowing to calculate thermal cycles of metal of the welded seam and heat affected zone for various distances between action zones of laser and additional heat sources, both for welding with deep penetration, and for the surface melting case [9], has been formulated on the basis of solution of the connected problems about radiation absorption, convective heat transfer, melt hydrodynamics, gas-dynamics of evaporation products and laser-induced plasma kinetics. The numerical scheme with explicit allocation of the welding bath border has been used in solving. The laser heating source in case of deep penetration has been described according to [10]. Essential difference in this case is presence of the second heat source distributed on the welding bath surface therefore use of assumption about two-dimensional heat transfer as it was made for laser welding becomes impossible. And so for hybrid welding there have been obtained a three-dimensional solution of thermal and hydrodynamic problems for the welding bath, taking into account influence of thermo capillary flow in the welding bath on the temperature distribution [11]. The target heating by the focused radiation of arc lamp lead to formation of the distributed moving heat source on the work piece surface. The source energy distribution is determined by local values of radiation intensity and radiation absorption factor depending on the surface temperature. Thus, the problem about heating a material by the lamp heat source is nonlinear since the heat source power depends on the surface temperature. First we consider the problem as linear one. In this case, having used the known expression for the Green function of the three-dimensional problem about heat conductivity in moving coordinate system, for the lamp source heat field one can write:

$$T(x,y,z) = \iint \frac{A(T(x',y'))I(x',y')}{2\pi\lambda\left|\vec{R}-\vec{R}'\right|} \exp\left(-\frac{v}{2\chi}\left(\left|\vec{R}-\vec{R}'\right| + (x-x')\right)\right) dx'dy'$$

where integration is fulfilled with respect of the target surface illuminated by lamp light. Considering the temperature dependence of absorption factor this expression is an integral equation for which solution the following algorithm has been developed: at the first stage the surface temperature is determined only. Calculating the integral by summation over two-dimensional grid we have got an algebraic nonlinear equation in each cell, and then it has been solved by the simpleiteration method. At that the local temperature in each cell of the surface grid has been determined and the local value of absorbed energy of the lamp radiation has been found with its help. Then, the heat field of the additional heat source is calculated with the known value of the absorbed energy distribution. This field without deep penetration has been summarized with a temperature field of the laser source. In deep penetration case the temperature distribution of the additional source has been considered in calculating of the cavity sizes and shape as a distributed heating temperature. The model realized as a computer program allows calculating size and shape of the welding bath, the temperature field and thermal cycles in the seam and heat affected zone. Comparison of the calculated results with experimental ones (fig. 2) confirms high accuracy of the developed model.

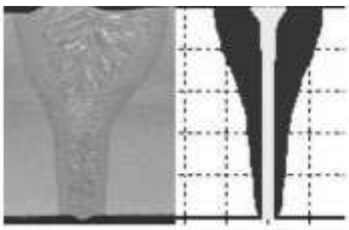


Fig. 2. Comparison of calculation results on the developed model (on the right) with experiment (on the left), laser radiation power – 20 kW, arc source power – 6 kW, melting depth – 24 mm.

Simulation of metal microstructure formation in hybrid welding Phase transformations in steels at the beam treatment defining the metal structure consist of two components. The first one is connected to decay (or formation) a solid solution of carbon in iron and formation (decay) of ferric carbide, and the second one is connected with crystal lattice transformation FCL-BCL at cooling and back at heating. To calculate parameters of carbide inclusions the kinetic model of formation and growth of the second phase inclusions for the solid solution decay has been developed. The kinetic model of the crystal lattice transformation (Į- Ûtransformation) has been formulated on the same principles, as the model of origin and growth of inclusions. Since the interphase border movement rate in this case is so that the diffusion Peclet number is not small, the diffusion equation, as against a problem about carbides growth, has been solved with considering a convective term. On the other hand, as the grain sizes in growing considerably exceeds a diffusion layer thickness the diffusion problem has been considered as one-dimensional. The joint solution of the connected problems about kinetics of growth of new phase grains and about carbon diffusion before its front allows calculating quantity of a new phase at any moment of a thermal cycle. Thus there has been obtained the self-consistent equations system describing completely material microstructure formation at high-speed heating and cooling. As parameters of initial metal structure there are taken into account both the initial carbides sizes, and the initial grains sizes influencing on the diffusion factor. An in parameter of model is the thermal cycle which parameters are defined by a technological mode of processing. The obtained solution allows calculating evolution of the metal phase composition in the processing zone. At the set degree of transformation completeness the model equations describe a full thermo kinetic diagram of austenite decomposition. It allows using existent methods of quantitative forecasting of phase composition and microstructure on the basis of such diagrams for the beam processing case [12].

Experimental set-up for pulse-periodic laser-arc welding the experimental stand shown on fig. 3, has been assembled on the basis of the pulse-periodic Nd:YAG - laser SCAT and plasmatron with direct arc developed by E.O. Paton Electric Welding Institute.

a) b)

Fig. 3. a) A view of the experimental stand for laser-arc treatment; b) Results of experiments on laser-microplasma welding. The arrow shows the moment of laser switching on. On the right of the arrow - microplasma action, on the left – laser-microplasma action.

The main heating of the work material here is provided by rather inexpensive energy of arc. Presence of laser radiation in the field of processing allows improving considerably quality of the arc heating source (fig. 3.). The experiments show, that addition of pulse laser radiation has allowed stabilizing considerably burning of the arc and as consequence to raise rate and quality of processing.

Experimental installation for research of laser-light welding process The experimental stand shown on fig. 4, has been assembled on the basis of the pulse-periodic Nd:YAG - laser QUANT 15 and an arc light radiator manufactured by SWAR firm. To feed laser radiation there has been used a specially developed mirror beam guide. The radiator design allows changing combination and pressure of working gas, and the welding head allows changing positional relationship of "laser" and "light" spots on the welded samples surfaces.

Fig. 4. The laser-light module for the hybrid welding technology

To optimize lamp parameters there has been fulfilled a calculation to define its power, heating spot diameter, and distance centre to centre of heating spots of light and laser beams, on which the highest efficiency of welding process with using the qЈ2-laser is reached. Light radiation power, thickness of welded plates, heating spot diameter of the light source, welding speed, distancecentre to centre of the heating spots of laser and light sources, plasma formative gas have been varied.

The mathematical model described above provides recalculation of the electric power input on electrodes of the polychromatic radiator into the power got in the focal spot on welded metal, therefore easily fixed power value on the radiator electrodes is used in calculated dependences for simplicity. Calculations have been carried out for steels type 30HGCA, type 347, aluminum and the titanium with thickness of 0.5 and 0.8 mm. The typical calculation example is shown on figure 5. The analysis shows, that in all the investigated range the effect of the greatest increase of melting efficiency is observed at light beam diameter of 0,3-0,5 cm in shifting the spot centers of laser and lamp beams on the target on -0,25 - +0,25 cm.

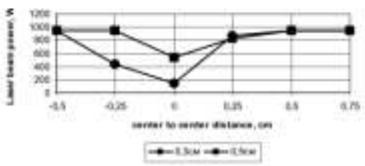


Fig. 5. Power of the laser radiation necessary for full penetration of sheet of steel 30HGCA of 0,8mm thickness, welding speed 2 cm/s, lamp power 3 kW, depending on distance centre to centre of heating spots of the laser and light sources for various spot diameters of the light source. Lamp gas - Xe

Also there has been investigated influence of light radiation heating on efficiency of laser melting of material at varying light source power used for heating. The calculated results, which examples are shown on fig.6, testify to essential increase of the welding speed providing through penetration for all investigated thickness and materials in using an additional heat source as a polychromatic radiator. From the data obtained it is seen, that in increasing thickness of welded plates effect of preheating decreases. The physical reason of this phenomenon is connected to that heating influence is limited by heating depth by heat transfer mechanism.The analysis of calculation results shows, that in the investigated range the greatest increase of melting efficiency is observed at the light beam diameter of 0,3-0,5 cm, shift of the radiation centers of the YAG:Nd-laser and the lamp within (-0,25 - +0,25) cm and electric power of the lamp 3000 - 5000 W. It is possible to conclude, that use of arc lamp allows increasing essentially welding speed for steels and aluminum alloys for the case of welding of small thickness. The fulfilled calculations have shown that Xe is the most effective as a lamp plasma gas. Comparison of calculation results at hybrid laser-light action on the thin sheet materials with experimental ones shows that the developed mathematical model provides sufficient accuracy of calculations, the relative error value do not exceed 10 % in calculating the melting area. Structure and properties of the weld metal at laser-light welding Taking into account tendencies of motor-car industry to manufacturing extra light car bodies due to use of the thin sheet high-strength low-carbon steels with breaking point up to 800-1000 ΕPa, with simultaneous decrease of their thickness to 0,5 mm, a high-strength low-carbon steel 30HGSA with breaking point 1080 ΕPa has been chosen for researches. Changing the form of a temperature cycle, it is possible to achieve both size reduction, and enlargement of the carbide inclusions in comparison with a temperature cycle, which is typical for laser action without an additional heat source (see fig. 7 - 8).

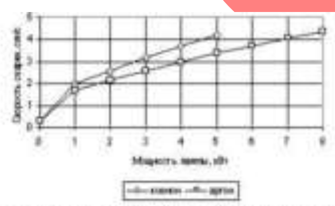
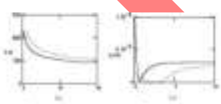
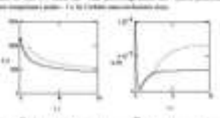
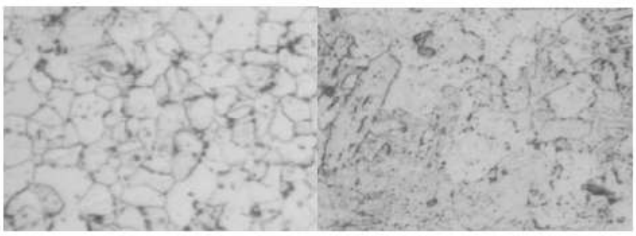


Fig. 6. Comparative influence of power of the polychromatic radiator with xenon and argon on the welding speed for steel of type 30HGSA at 0.3 mm.







a) b)

Fig.9. - Microstructure after hybrid action, the maximal heating temperature is 1200 K, field width 50 microns;
a) Processing speed 2 mm/s, b) Processing speed 4 mm/s.

It is obvious that decrease of the time delay between peaks results in significant size reduction of the carbide inclusions as it is predicted by the developed theory. The analysis of distribution of micro hardness average values on researched welds has shown that the samples welded by hybrid welding are characterized by considerably smaller difference of the micro hardness values in comparison to the samples welded by laser welding. Decrease of marten site part in weld metal allows raising its plasticity. To research influence of pass from laser welding to the hybrid laser-light one on the technological plasticity, the welded samples have been tested by the Ericson method. The carried out experiments have shown, that for steel 30HGSA pass from laser to hybrid welding increases technological plasticity more than by 40 %.

1.2 Conclusions

1. Use of the hybrid laser-arc or laser-light welding instead of laser one allows to increase the melting efficiency and to provide stability of weld formation at welding metals of small thickness.

2. The laser-light welding variant with accompanying heat treatment in the investigated range of modes allows increasing deep drawing depth and, accordingly, improves punch ability of the welds. The maximum value of the deep drawing depth has been observed when the axis of the focal spot of the laser beam has displaced from the light spot axis on 1.0-1.5 mm.

3. The analysis of a microstructure allows concluding that improvement of punch ability after the laser-light welding results from decrease of the marten site part in the metal microstructure of the weld and heat-affected zone. It can be explained by influence of accompanying stress relieving due to action of the polychromatic heat source.

4. Character of micro hardness change in welds after the laser-light welding in comparison with laser one allows to note significant decrease of micro hardness variation on the heat affected zone and decrease of the maximum values of the metal micro hardness in the weld and heat affected zone.

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