ISSN 1392-1207. MECHANIKA. 2005. Nr.2(52)

Investigation of an impulse laser welding of thin plate constructions from different steels

I. Vishniakas
Vilnius Gediminas Technical University, Basanavičiaus 28, LT-03324 Vilnius, Lithuania, E-mail: ivanas@me.vtu.lt

1. Introduction

In the electronic devices it is frequently necessary to connect thin-walled constructions from different metals. To connect such constructions is possible by different methods: by welding, by soldering, by riveting. Each method has its advantages and deficiencies. The construction is over-heated during the soldering, it negatively effects electronics. Riveting in the instrument manufacture barely adapts because of the equipment of large sizes used and low effectiveness in its work. Laser welding is the most technological method of connecting thin-walled constructions from different metals. It makes it possible to obtain full fusion with a minimum quantity of molten metal [1-5]. Two types of lasers commonly are used for the welding: gas lasers and solid-state lasers. Gas lasers have higher efficiency (to 30%) and a more complex construction. Solid-state lasers have low efficiency (1-3%), however, they have more simple construction and therefore they are more reliable [6-13].

Methods of the investigation of different steels welding can be conditionally divided into three large groups. The first group includes investigation methods, related with the process of welded joint formation of different metals (i.e., simulation of the welding process). The second group includes the methods of study of the molded welded joint of different metals (structural changes, the redistribution of chemical elements, diffusion and so on). The third group includes workability investigations related with the workability determination of the welded joint (strength, sealing characteristics, stability to vibrations, corrosion resistance, etc.).

2. Experimental research

An investigation of butt welding of the plates made of carbon steel 65Г GOST of 1577-81 (65Mn4 LST EN 10027-1) with steel 07X16H6 GOST 5632-72 (X7CrNi16-6 LST EN 10027-1) were carried out. Thickness of the plates was 0.30 and 0.25 mm. The pulsed ruby laser was used for welding. Its basis is synthetic ruby, consisting of Al_2O_3, alloyed by 0.05% Cr.

Basic parameters of laser welding are [4]: a pulse energy, welding and pulse frequency rate. The pulse frequency of welding was maintained constant and was equal to 15 Hz; the speed and energy of welding were changed.

Pulse energy can be calculated using the following formula

$$W = \frac{0.885 T \lambda \tau r^2}{\sqrt{a \tau}} \tag{1}$$

where T is melting point of the metal; λ is thermal conductivity of the metal; τ is pulse duration; r is a radius of laser beam at the point of heating; a is the coefficient of thermal diffusivity.

Pulse duration is usually established experimentally. This depends on chemical composition of the metal and its thickness. It is important, that during welding the metal in weld metal zone of connections would be completely melted, but not sprayed. The radius of the focused beam depends linearly on the laser power. When the beam radius is greater, the density energy is lower and the penetration depth of the metal is lower. The rate of welding – on it depends the degree of overlapping of pulses (points) – can be calculated using the formula

$$v = df(1 - k) \tag{2}$$

where d is the diameter of pulse; f is the pulse frequency; k is the factor of overlaping.

The schematic of plates fastening before welding is shown in Fig. 1. Chemical composition was determined by microscope Spectro LAB 05 3/N 45/2b3. Samples were cut out from the weld metal and micro sections were prepared. Metallographical investigations of cros-sections of the weld were performed with the help of optical microscope LEICA MEF 4M as well as scanning electron microscope XL 30 ESEM, PHILIPS.

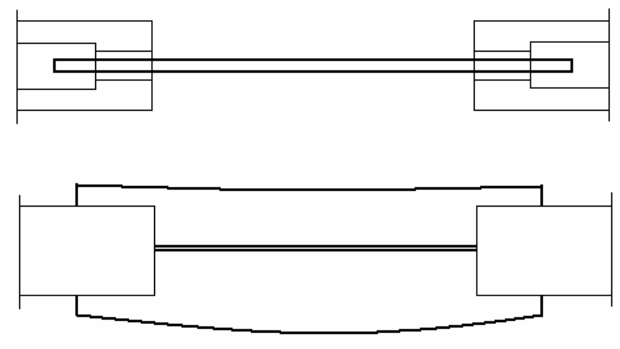

Fig. 1 Schematic of plates fastening before welding

3. Results and their analysis

The obtained samples were investigated in the following way: the quality of samples visually was determined (LST EN 970); then they were bent in the transverse and longitudinal direction and angle of curvature was determined; microsections were manufactured from these obtained models and the microstructure of the weld and the zone near the weld was determined.

Chemical composition of base metal and weld material is given in Table 1. Welding conditions are given in Table 2. Results of static bending of samples are given in Table 3.

Steels 65Г and 07Х16Н6 are of different structural classes (pearlitic and austenitic-martensitic). The following difficulties appear during welding of steels of different structural classes [1-5] steels:

1) when there are large difference in melting points of metals then at the moment of reaching of the melting point one metal is melted and the other is still in solid;

2) a large difference in linear expansion coefficients of the combined metals specifies the appearance of significant thermal stresses;

3) differences between thermal conductivities and heat capacities of metals being welded lead to the change of temperature fields as well as crystallizing conditions of the weld;

4) differences in electromagnetic properties of the combined metals can lead to unsatisfactory formation of the weld;

5) chemical composition of generatrix phases renders the decesive influence on the character of the welded joint formation.

Table 1

Chemical composition of base metal and weld metal, %

Material	*C*	*Mn*	*Si*	*Cr*	*Ni*	*Mo*	*Fe*
65Г	0.63	1.05	0.23	0.08	0.08	0.03	97.83
07Х16Н6	0.05	0.81	0.43	16.30	8.50	0.07	73.61
Weld metal	0.34	0.93	0.33	8.19	4.29	0.05	85.72

Table 2

Regimes of the laser welding

n	*Q*, J	*v*, mm/s	*Q/v*, Js/mm
1	5.50	1.5	3.67
2	5.95	1.5	3.97
3	6.38	1.5	4.25
4	6.66	1.5	4.44
5	7.08	1.5	4.72
6	6.38	1.35	4.73
7	6.38	1.65	3.87
8	6.38	1.80	3.54

Table 3

Results of static bending of the samples

n	across the weld, $\alpha°$	along the weld, $\alpha°$	*Q/V*, Js/mm
1	180	120	3.67
2	180	110	3.97
3	160	110	4.25
4	140	100	4.44
5	125	90	4.72
6	120	75	4.73
7	170	120	3.87
8	180	125	3.54

When different metals are welded phase and structural transformations, which take place during the cooling process of the solid solution of the weld can lead to cold cracking. Such transformations are accompanied by significant distortions of crystal lattice and the volumetric changes (martensitic transformation in steels of pearlitic and martensitic classes). Furthermore, during welding of the metals which thermal and electromagnetic properties distinquish significantly, difficulties related with different areas and penetration depth appear (smelting of steel 09Г2С takes place twice more often than that of 12Х18Н10Т).

The tendency appearance of cracks in steel the cooling the is estimated by the coefficient *Pcm* [4]

$$Pcm = \%C + \%Si/30 + \% (Mn + Cr + Cu)/20 + +\%Ni/60 + \%Mo/15 + \%V \quad (3)$$

When $Pcm \leq 0.35$ the steel is not liable to the cracks; when $Pcm > 0.35$ the steel is liable to the cracks.

Since in the case of the laser welding without the addition of weld material the weld consists of both steels in equal parts, we will obtain *Pcm* = 0.89%. This shows, that the weld metal is liable to crack formation.

The obtained results are presented graphically in Figs. 2-4.

As it can be seen from Figs. 2-4 the angle of curvature of welded plates grows when decreasing welding energy and increasing welding rate. However, in this case the quantity of molten metal and the depth of penetration decreases. Therefore it is necessary to select such technological regimes, that the necessary smelting occurs with the minimum energy and maximum speed of welding.

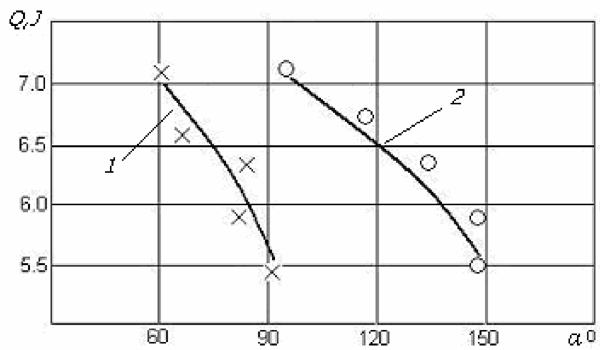

Fig. 2 Dependence of the welding energy on angle of curvature (v = 1.5 mm/s): *1* - across the weld; *2* - along the weld

As a special feature of the formation of weld material composition at fusion welding of different metals is the inevitability of passage formation from one composition of metal to another, i.e. the specific chemical heterogeneity of the weld material composition appears.

During welding of steels the welded joint consists of several zones: the zone of welded materials (the region of mixing), the zone without materials mixing, the zone of partial melting, the boundary of base metal with the weld, the heat affected zone and the zone of the base metal which is not subjected to thermal influence.

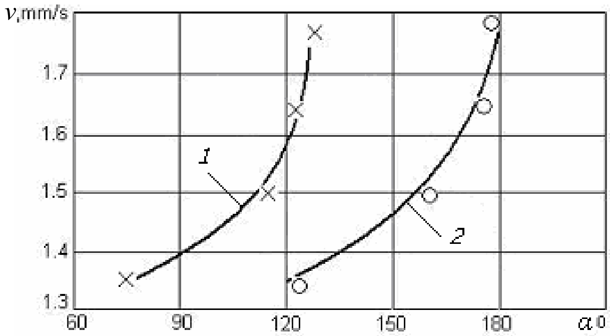

Fig. 3 Dependence of the welding energy on angle of curvature (Q = 6.38 J): *1* - across the weld; *2* - along the weld

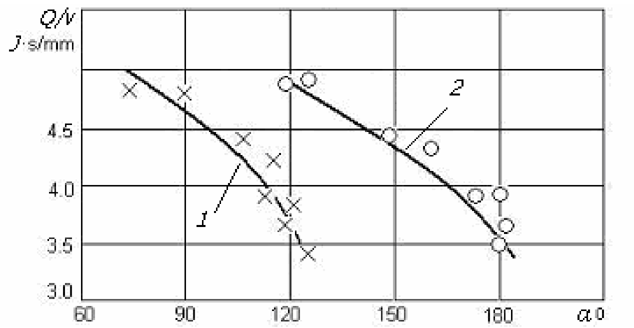

Fig. 4 Dependence of the welding energy on angle of curvature (Q/V): *1* - across the weld; *2* - along the weld

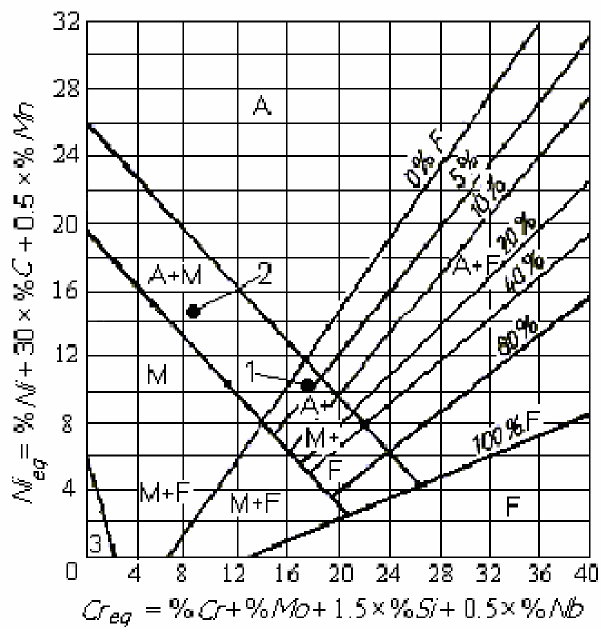

Fig. 5 Structures of welded seams on Sheffler diagram at welding steel [5]: *1* - steel 07X16H6; *2* - weld metal

The structure of welded metal can be determined by using Sheffler diagram taking average values of *Ni* and *Cr* (Fig. 5).

$$Nieq = \text{of}\ \%\ Ni + 30\ \%\ C + 0.5\ \%\ Mn \quad (4)$$

$$Creq = \text{of}\ \%\ Cr + 1.5\ \%\ Si + +\%\ Mo + 0.5\ \%\ Nb \quad (5)$$

Steel 07X16H6: *Nieq* = 10.40%; *Creq* = 17.14%. Weld metal: *Nieq* = 14.96%; *Creq* = 8.78%.

Using Sheffler diagram for the determination of composition phase of the weld in the case carbon steel welding with an austenitic one, we can see that the structure contains 90% of an austenite and 10% of ferrite. The martensite in this case is entirely excluded. Therefore it may be expected that the formation of cracks in the weld metal is nearly impossible when the weld is formed by welding different metals using austenitic electrodes. By the way, in practice during austenitic steel welding with carbon steel in the weld metal and also in the fusion zone, cracks sometimes appear.

In Figs. 6-11 macro and microstructures of the welded joints of carbon and chrome-nickel steel are presented. As it can be seen from figures shown the increased energy of welding causes overheating of weld material and crack formation. During welding from the side of steel 65Г under all welding conditions in the heat-affected zone of steel the zone of the increased etchability of metal is observed. This shows that a part of carbon had penetrated into the weld material and increased its hardness also the possibility of martensitic structure formation.

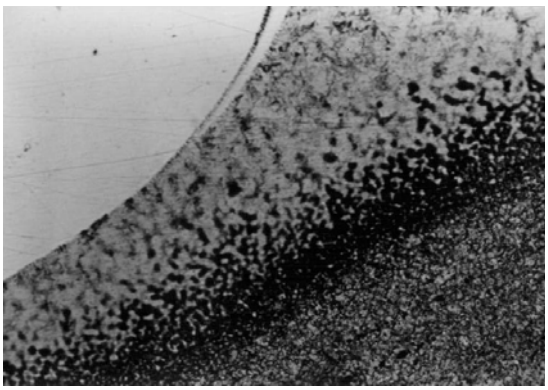

Fig. 6 Heat affected zone between steel 65Г and the weld with welding energy of 6.66 J and the speed 1.5 mm/s; increased 400 times

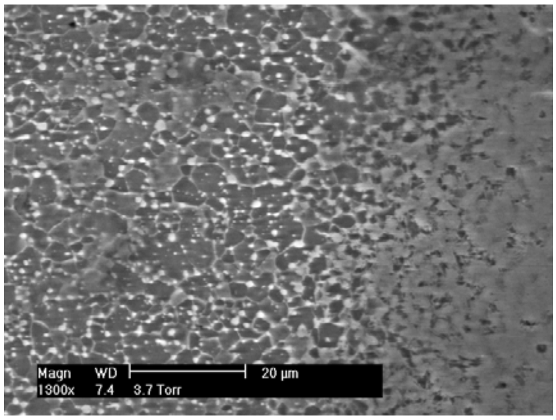

Fig. 7 Dilution zone between steel 65Г and the weld with welding energy of 5.50 J and the speed 1.5 mm/s

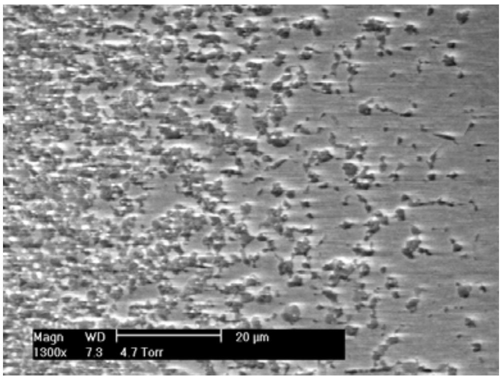

Fig. 8 Dilution zone between steel 65Г and the weld with welding energy of welding 7.08 J and the speed 1.5 mm/s

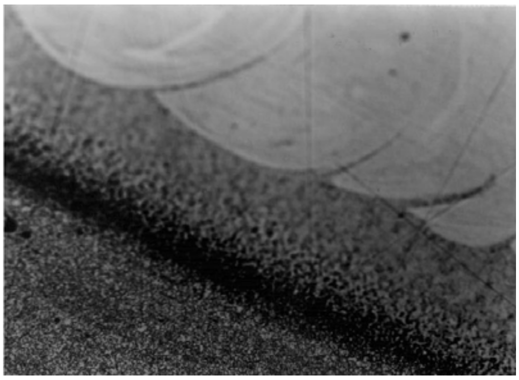

Fig. 9 Heat-affected zone between steel 65Г and the weld with welding energy of 6.38 J and the speed 1.65 mm/s; increased 200 times

Fig. 10 Macrostructure of the weld with welding enerrgy of 6.38 J, welding rate is changed from 1.35 mm/s (above) to 1.80 mm/s (below); increased 25 times

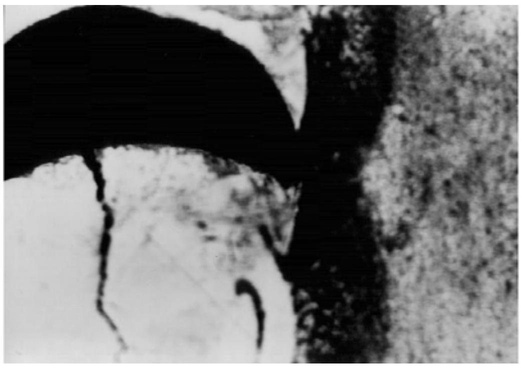

Fig. 11 Crack, formed from the burn with welding energy of 7.08 J and the speed 1.50 mm/s; increased 200 times

4. Conclusions

1. At pulse laser welding steels 65Г and 07X16H6 maximum angle of curvature (180° in transverse and 125° longitudal direction) is obtained with minimum linear energy (3.54 Js/mm).
2. At pulse laser welding steels 65Г and 07X16H6 the zone with the increased etchability (with the reduced carbon content) in the heat-affected zone from the side steel 65Г is observed.
3. The burns and sometimes crack can be observed in the weld during welding of 65Г and 07X16H6 steels with the increased energy or the low rate of the laser welding.

References

1. **Рябов В.Р., Рябкин Д.М., Курочко Р.С., Стрижевская Л.Г.** Сварка разнородных металлов и сплавов.-Москва: Машиностроение, 1984.-239с.
2. **Vishniakas, I.** The structure of welded austenitic and non-austenitic steel joints.-Materials Science (Medžiagotyra). 2003, No9(2), p.174-177.
3. **Vishniakas, I.**. Research of peculiarities of steel 10X2M welding with other sreels.-J. of Vibroengineering.-Vilnius 2003, v.5, No1, p.39 -42.
4. **Vishniakas, I.** Influence of structure of welded connections from a heat resistant steel on their reliability. -Materials Science (Medžiagotyra), 2004, No10(3), p.206-210.
5. **Vishniakas, I.** Analysis of chemical elements distribution in carbon steel layer welded by austenitic electrods.-Mechanika.-Kaunas: Technologija, 2004. Nr.4(48), p.64-67.
6. **Shrier, L., Jarman, R.A., Burstein, G.T.** Corrosion. University of Cambridge. 1994, v.2.-1408p.
7. ASM International. Metals Handbook.-USA, 2000. v.9.-775p.
8. **Ambroza, P., Kavaliauskienė**, L. Influence of Carbon and Boron on the Properties of Deposited Layer. ISSN 1392-1207-Mechanika.-Kaunas: Technologija, 2004. Nr.4(48), p.59-63.
9. **Арзамасов Б.Н.** и др. Материаловедение. 3-е издание, исправленное и дополненное.-Москва: И-во МГТУ им. Баумана, 2002.-648с.
10. **Винокуров В.А.** и др. Сварные конструкции. Механика разрушения и критерии работоспособности.-Москва: Машиностроение. 1996.-576с.
11. Новые материалы. Колл. Авторов. Под научной редакцией **Ю.С.Карабасова**.-Москва: МИСИС.-2002.-736 с.
12. **Шлямнев А.П., Свистунова Т.В., Лапшина О.Б.** Коррозионностойкие, жаростойкие и высокопрочные стали и сплавы: Справочник.-Москва: Интермет инжиниринг, 2000.-232с.
13. Суперсплавы II: Жаропрочные материалы для аэрокосмических и прпомышленных энергоустановок/ Под ред. **Ч.Т.Симса, И.О.Столоффа, У.К.Хагеля;** Пер. С англ. В 2-х кн. Кн.1/ Под ред. **Р.Е.Шалина**.-Москва: Металлургия, 1995.-384с.

I. Višniakas

SKIRTINGŲ PLIENŲ PLONASIENIŲ KONSTRUKCIJŲ SUVIRINIMO IMPULSINIU LAZERIU TYRIMAS

R e z i u m ė

Tiriamas 0.30 mm storio perlitinio plieno 65Г (65Mn4 LST EN 10027-1) lazerinis suvirinimas su austenitiniu-martensitiniu plienu 07X16H6 (X7CrNi 16-6 LST EN 10027-1), kurio storis 0.25 mm. Naudojamas rubino impulsinis lazeris. Impulsų dažnis – 15 Hz, galia buvo keičiama nuo 5.50 iki 7.08 J, suvirinimo greitis – nuo 1.35 iki 1.80 mm/s. Buvo nustatomas suvirintųjų pavyzdžių lenkimo kampas ir tiriama suvirintųjų siūlių metalografija. Metalografiniai tyrimai rodo, kad terminio poveikio srityje iš anglinio plieno 65Г pusės pastebima sritis su mažesniu anglies kiekiu (ji geriau ėsdinasi). Nustatyta, kad geriausi lenkimo rezultatai gaunami esant minimaliai linijinei suvirinimo energijai. Kai suvirinimo režimai skiriasi nuo optimalių, siūlėje atsiranda porų ir plyšių. Tai blogina suvirinto sujungimo patikimumą ir eksploatacines savybes. Geriau virinti esant nedideliam poslinkiui į labiau legiruoto metalo pusę.

I.Vishniakas

INVESTIGATION OF AN IMPULSE LASER WELDING OF THIN PLATE CONSTRUCTIONS FROM DIFFERENT STEELS

S u m m a r y

The investigation of laser welding of pearlitic steel 65Г (65Mn4 LST EN 10027-1) of 0.30 mm thickness with austenite-martensite steel 07X16H6 (X7CrNi 16-6 LST EN 10027-1) of 0.25 mm thickness was carried out. The ruby laser was used. The pulse frequency was 15 Hz and the power varied from 5.50 to 7.08 J, the used welding rate was from 1.35 till 1.80 mm/s. The angle of curvature of the welded samples was determined and metallography of the welds was investigated. It is established, that the best results of the samples bending are obtained when linear energy of welding is minimal. Metallgraphcal investigations show, that in the thermal influence zone the region from the side of carbon steel 65Г the diminished carbon content is found (it etches better). Pores and cracks are observed in the weld when the deviation from the optimum welding conditions takes place in the weld. This makes reliability and exploiting properties of the joint worser. It is the best to conduct the welding with a small displacement to the side of more alloyed steel.

И. Вишнякас

ИССЛЕДОВАНИЕ ИМПУЛЬСНОЙ ЛАЗЕРНОЙ СВАРКИ ТОНКОСТЕННЫХ КОНСТРУКЦИЙ ИЗ РАЗНЫХ СТАЛЕЙ

Р е з ю м е

Проведено исследование лазерной сварки перлитной стали 65Г (65Mn4 LST EN 10027-1) толщиной 0.30 мм с аустенитно-мартенситной сталью 07X16H6 (X7CrNi 16-6 LST EN 10027-1) толщиной 0.25 мм. Использовался рубиновый лазер. Частота импульсов – 15 Hz, мощность изменялась от 5.50 до 7.08 Дж, скорость сварки – от 1.35 до 1.80 мм/с. Определялся угол изгиба сваренных образцов и исследовалась металлография сварных швов. Установлено, что наилучшие результаты изгиба образцов получены при минимальной погонной энергии сварки. Металлографические исследования показали, что в зоне термического влияния со стороны углеродистой стали 65Г наблюдается зона с пониженным содержанием углерода (она сильнее травится). При отклонении от оптимального режима сварки в шве наблюдаются поры и трещины. Это снижает надежность и эксплуатационные свойства сварного соединения. Сварку лучше всего вести с небольшим смещением в сторону более легированной стали.

Received November 23, 2004