THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N°. 2 - 2024, ISSN 2668-4748; e-ISSN 2668-4756
Article DOI: https://doi.org/10.35219/mms.2024.2.01

EXPERIMENTAL RESEARCH ON MODIFICATION OF MECHANICAL PROPERTIES VALUES FOR HEAT TREATED WELDED JOINTS

Marian-Iulian NEACȘU
"Dunarea de Jos" University of Galati, Romania
e-mail: mneacsu@ugal.ro

ABSTRACT

This paper presents the results of studies and research on the values of the mechanical properties of welded joints on OLC 20 and OLC 25 steel samples, in the case that no heat treatment is performed on them and in several cases when the samples are heat treated after welding. After welding and heat treatments for normalization, hardening and tempering was carried out on the samples.

After performing the heat treatments, the researched samples were subjected to tests to determine: Vickers hardness, mechanical resistance Rm and breaking energy KV.

Analysing the obtained results, it can be concluded that following the thermal normalization treatment, the optimal complex of the values of the studied mechanical properties was obtained.

KEYWORDS: welding, heat treatment, hardness, mechanical resistance, breaking energy

1. Introduction

The superior valorisation of metallic materials imposes special qualitative tasks in the entire industrial and scientific metallurgical activity currently oriented towards the adoption of those modern technologies that allow the reduction of metal consumption, the increase of the durability and performance of the highly technical products specified to be realized in the construction of machines, aeronautics, electronics and energy.

Countries with highly developed economies leave their mark on the global economy and try to consolidate their position in a very dynamic and highly competitive market. This desire can only be achieved by permanently investing in research and by streamlining industrial production, which holds the majority of the country's gross income. An important role in this competition is also the training of specialists, who can contribute directly to the increase in the quality of products, in conditions of economic efficiency. Thus, it follows the importance of evaluating the economic contribution and the impact on the productivity of welding materials, in the industrial branches where welding is a key element in the manufacturing process. If there is still some scepticism about this, we can mention that in the US, durable industrial goods where welding is a critical component in the manufacturing process, these goods represent 90% of all manufactured industrial goods [1, 2].

According to the same report, the industrial branches in which the welding of materials is a key element in the manufacturing process represent 59 % of the total industrial production [1].

Increasing the degree of complexity and product typification actions, optimizing the activity of choosing or assimilating new brands of alloys involves a process of qualitative renewal of both domestic metal production and scientific thinking in the field of elaboration and processing of metallic materials [3].

Over 70 % of the total welding expenses are held by labour expenses. In this context, it is easy to understand that these industrial fields, dominated by welding technologies, have a major contribution to the gross domestic product (GDP) of industrially developed countries and are strategic sectors that ensure a positive trade balance. The interest given to improving the global competitiveness of these industries with a major impact on the economy is obvious, this being achieved mainly by increasing the performance and profitability of companies, which are based on welding technologies [4].

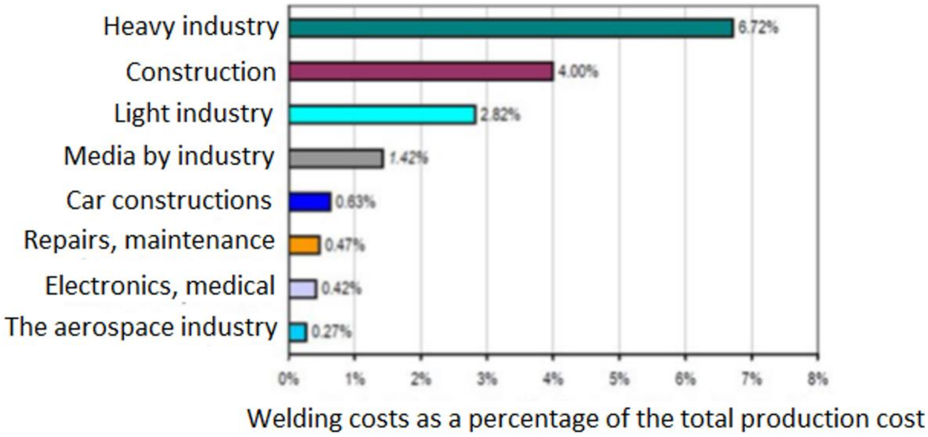

Fig. 1. *The share of welding costs from the total production costs* [1]

The properties imposed on steel products intended for the realization of various metal constructions undergo changes, more or less important, as a result of the subsequent processing to which they are subjected. Steels undergo the greatest changes due to the action of welding thermal cycles as a result of rapid heating during welding and the thermal conductivity of the base metal, hard constituents with reduced ductility appear in the affected area. The ability of a heat affected zone and weld bead to respond to heat treatment without compromising the strength of the welded structure is a common area of research for steel and filler manufacturers, designers and builders [5].

The welded joints were executed on the base metal, so the entire welded structure is required to withstand the stresses foreseen in operation. The satisfaction of this condition, however, depends on the welding behavior of the steels, which cannot be guaranteed for all welding processes, depending on both the base metal and the geometry of the joint, the manufacturing conditions and the service regime of the welded assembly. The risk of brittle fracture of welded joints has determined the initiation of extensive research, which resulted in the design of a great diversity of tests and criteria for interpreting the results. However, there are serious difficulties in assessing the reduction in brittle fracture resistance of steels, as a result of the hardening they undergo under the action of the welding process [6].

Steels for constructions and welded structures are those steels that are used in the manufacture by welding of structures that are especially mechanically stressed and operated at temperatures between -50 °C and +50 °C. They must satisfy three fundamental requirements [7, 8]:

- to weld well with relatively simple and high productivity procedures.
- to have as high mechanical characteristics as possible to create light structures;
- to be cheap so as not to make the structure more expensive;

According to the specifics of the operating conditions, the following categories of steel for construction and welded structures appear [9, 10]:

• steels for general use;
• steels for devices and containers under pressure;
• steels for shipbuilding and marine platforms.

The separation between these groups results from the differences in operating characteristics and quality control rules.

The problem of the choice of filler materials is generally complex and considers ensuring in the weld some strength characteristics at least equal to those of the base metal and a chemical homogeneity acceptable from a functional and economic point of view.

Apart from these general criteria, the compatibility between the base metal (MB) and the filler metal (MA) must also be considered. By this, it is meant the property of a filler metal (MA) to couple with a certain steel, under certain welding conditions, to make a welded joint that corresponds to the required technical and functional characteristics. In general, filler materials are produced in the form of electrodes, wires and fluxes for welding [11].

2. Experimental conditions

The experimental material is represented by two samples welded by the manual electric process, the base material consisting of two raw forged and machined plates with a thickness of 20 mm and a length of 500 mm.

The quality of the base material is OLC 20 for the first sample, respectively OLC 25 for the other, the welding being performed with covered electrodes type E 424B42H10 in both cases [11, 12].

THE ANNALS OF “DUNAREA DE JOS” UNIVERSITY OF GALATI
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
Nº. 2 - 2024, ISSN 2668-4748; e-ISSN 2668-4756
Article DOI: https://doi.org/10.35219/mms.2024.2.01

The chemical composition and mechanical property values for the base material, in the as-forged state, are shown in table 1 (Chemical composition) and table 2 (Mechanical property values).

Table 1. *Chemical composition of the base material*

	C	Mn	Si	S	P	Cr	Ni	Cu	Al
OLC 20	0.21	0.42	0.26	0.024	0.014	0.21	0.19	0.3	0.026
OLC 25	0.23	0.50	0.28	0.007	0.011	0.19	0.17	0.03	0.031

Table 2. *Values of mechanical properties* [13]

	$Rp_{0,2}$ [MPa]	Rm [MPa]	A [%]	KV [Joule]
OLC 20	277	433	25	30
OLC 25	291	453	23	28

Table 3. *Chemical composition and mechanical characteristics for the filler material* [13]

Chemical composition [%]				
C=0.071	Mn=0.792	Si=0.331	P=0.009	S=0.021
Mechanical tests				
$Rp_{0,2}$ [MPa]	**Rm [MPa]**	**A [%]**	**KV (Joule)**	
471	586	29	214	

Mechanical tests or carried out at room temperature, in accordance with the applicable standards SR EN 10002/1:2002 (tensile test) [14] and SR EN 10045/1:1993 (shock bending test) [15]. The chemical composition and mechanical characteristics for the aggregate material are certified by their manufacturer, as shown in Table 3.

The specification of the welding process used is as follows:

• preheating temperature 120 ± 10 °C;

• temperature between layers 200 ± 15 °C;

• current intensity and arc voltage for the root layer: I1 = 90 ± 5 A;

Ul = 22 ± 1 V;

• current intensity and arc voltage for the filling layer: I2 = 125 ± 5 A;

U2 = 23 ± 1 V.

In many cases, the application of a heat treatment ensures the joining by welding of steels considered non-weldable or difficult to weld without it.

Currently, it is believed that with any properly prepared and processed steel, a welding technology can be established that allows obtaining the operational characteristics required for the welded joint.

Since the welding process involves rapid heating and cooling of the material, it can be compared to the action of a thermal shock. The ability of the material to withstand shock action without degrading defines its weldability. The action of thermal shock can decrease in intensity by applying a certain type of heat treatment.

The following post-weld heat treatments were applied to the investigated steels, OLC 20 and OLC 25: normalizing, and tempering.

In order to improve the metallurgical structure and implicitly the mechanical properties, a thermal normalization treatment was carried out, identical for the two samples:

• heating speed 80 °C/h;
• maintenance temperature 915 °C;
• holding time 30 minutes;
• cooling in still air.

The tempering parameters were as follows:

• heating speed 80 °C/h;
• maintenance temperature 860 °C;
• holding time 15 minutes;
• cooling in oil.

Next, the evolution of the mechanical properties of the joints was followed by applying an annealing heat treatment with the following parameters:

• heating speed 80 °C/h;
• maintenance temperature 360 °C;
• holding time 15 minutes;
• cooling in still air.

3. Results of experimental research

The initial mechanical characteristics of the welded and untreated samples, strength and toughness characteristics were verified. For this, the following tests were performed at room temperature:

a) transverse tensile test, according to SR EN 10002/1:2002 [14];

b) shock bending test, according to SR EN 10045/1:1993 [15];

Nº. 2 - 2024, ISSN 2668-4748; e-ISSN 2668-4756
Article DOI: https://doi.org/10.35219/mms.2024.2.01

c) Vickers hardness test SR EN 1043-1:2004 [16];

d) mandrel bending test, according to SR EN ISO 156/4-1:2004 [17].

Bending on the mandrel was done on a mandrel with a diameter of D = 60 mm, as required in SR EN ISO 156/4-1:2004 which regulates the verification of the electric arc welding process of steels, determining the angle from which on a crack with a length of at least 2 mm is formed on the surface of the test piece.

The shock bending test was performed on sets of three ISO-V specimens, with the notch-oriented perpendicular to the face of the welded plate and centered successively in the base material, the heat-affected zone and the filler material. The positioning of the notch was achieved by attacking with Nital 2% reagents the samples flowed perpendicular to the weld bead and ground on the side faces to a cross section of 10 x 10 mm^2. The breaking energy was determined as the arithmetic mean of the values obtained on the set consisting of three samples from each area of interest.

The variation of the Vickers hardness in the joint section depending on the state of the samples, non-thermally treated or thermally treated, is shown in figure 2, 3 and 4 with the observation that the test load is 10 kgf and the working method is that of SR EN 1043-1:2004.

Comparing the hardness measurement results between untreated and heat-treated welded samples, it is obvious that the most convenient results are for normalized samples, but also the combination of hardening followed by tempering is a solution for improving the mechanical properties of the joint.

In the case of return, the hardness variation when passing from the base material to the heat-affected zone is 47 HV10 compared to 84 HV10 for OLC 20, respectively 60 HV10 compared to 110 HV10 for OLC 25. Although this ratio of approximately 2:1 is reduced sensitively, the variation of hardness when passing from the heat-affected zone to the filler material is less after the improvement treatment compared to the case of the untreated welded samples, 40 HV10 compared to 39 HV10 for OLC 20, respectively 59 HV10 compared to 76 HV10 for OLC 25.

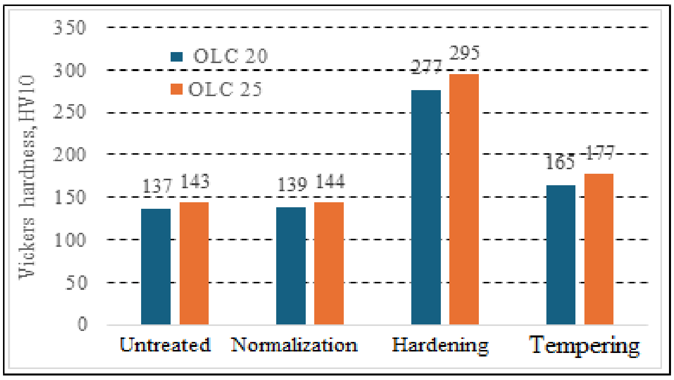

Fig. 2. *Variation of HV hardness in the MB area for the two investigated steel brands depending on the heat treatment applied*

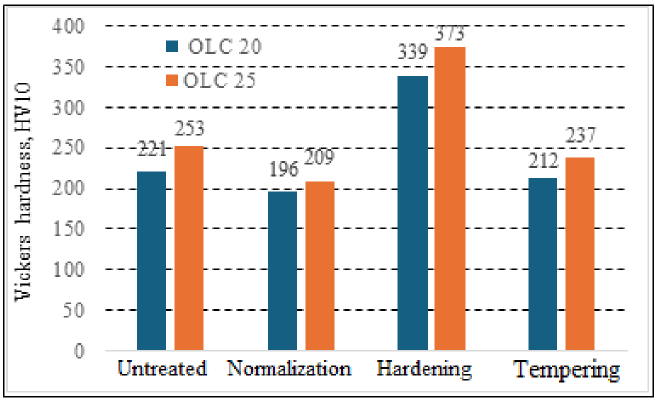

Fig. 3. *Variation of HV hardness in the ZIT zone for the two investigated steel brands depending on the heat treatment applied*

THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
Nº. 2 - 2024, ISSN 2668-4748; e-ISSN 2668-4756
Article DOI: https://doi.org/10.35219/mms.2024.2.01

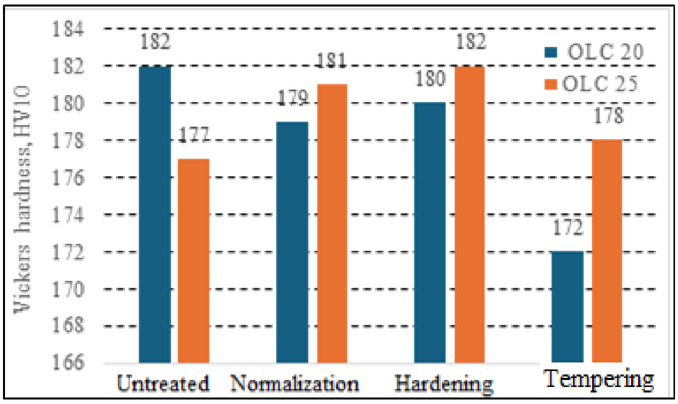

Fig. 4. *Variation of HV hardness in the MA area for the two investigated steel brands depending on the heat treatment applied*

The results of the fracture energy variation for the investigated samples are illustrated in the graphs in Figures 5, 6 and 7.

After analysing the data obtained for the breaking energy, it can be concluded that the values of the breaking energy are higher in the treated samples compared to the untreated samples. Overall, the toughness gain is more important after the normalizing heat treatment compared to the tempering heat treatment.

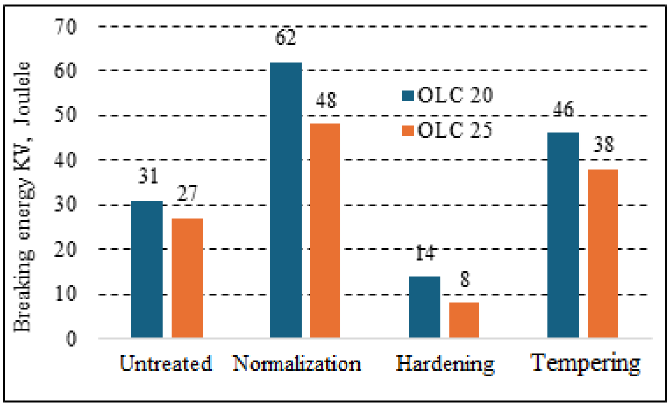

Fig. 5. *Variation of KV in the MB area for the two investigated steel grades depending on the heat treatment applied*

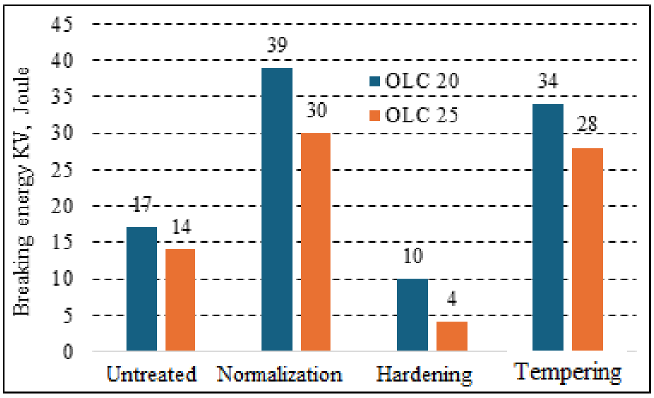

Fig. 6. *Variation of KV in the ZIT area for the two investigated steel brands depending on the heat treatment applied*

THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N°. 2 - 2024, ISSN 2668-4748; e-ISSN 2668-4756
Article DOI: https://doi.org/10.35219/mms.2024.2.01

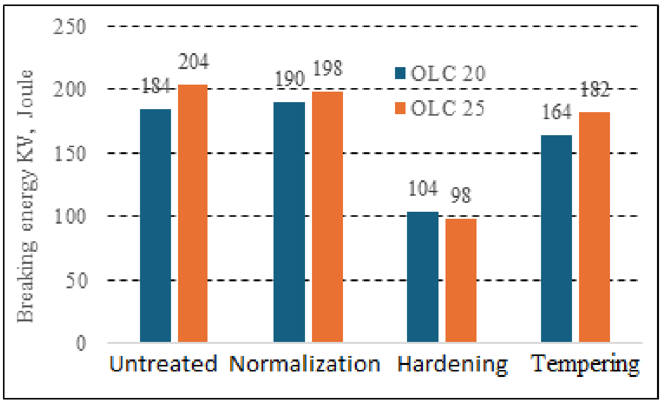

Fig. 7. *Variation of KV in the MA zone for the two investigated steel brands depending on the heat treatment applied*

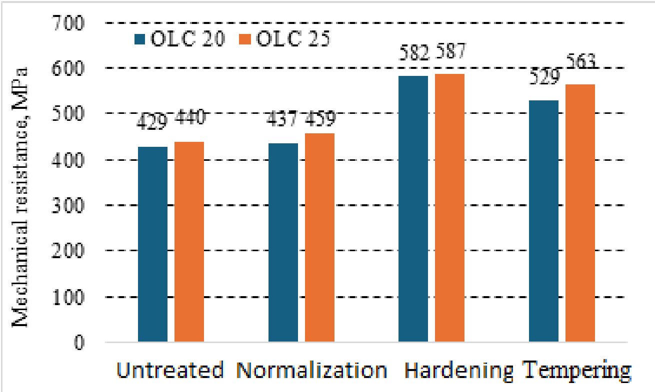

Fig. 8. *Rm variation for the two investigated steel grades depending on the heat treatment applied*

Figure 8 shows the variation in breaking strength depending on the state of the investigated samples (thermally treated or untreated). The highest values of the mechanical strength were obtained for the hardened samples, then for those subjected to the tempering treatment followed by the values of the normalized samples and the lowest values of the resistance were recorded for the non-thermally treated samples.

4. Conclusion

Relating the gain obtained in the improvement of the mechanical properties to the apparent expenses of the thermal treatments applied, it can be concluded that the optimal solution for the studied materials is the normalization thermal treatment, which leads to a satisfactory mechanical resistance, combined with a capacity for plastic deformation and a toughness that can be characterized as very good.

Taking into account the above, the positive influence of heat treatments results from normalization and recovery of the mechanical characteristics of welded joints with OLC 20 / OLC 25 base material.

By comparison with the results obtained after the normalization heat treatment, we find that the welded samples and to which an annealing heat treatment was applied have a superior mechanical strength, the break occurring in the base material at values above 500 MPa in each case. The superiority of the tempering heat treatment consists in obtaining a mechanical resistance to breaking higher by about 100 MPa compared to the normalizing heat treatment.

Under identical welding and heat treatment conditions, it was found that the normalizing heat treatment was superior to the annealing treatment in terms of joint toughness, while the plastic deformation capacity, tested by the mandrel bending test, remained satisfactory.

Comparing the results of the tests and examinations carried out for the two materials, we notice that in the conditions where the chemical composition does not apparently show significant differences, the welding behavior of the OLC 20 material is significantly superior to the OLC 25

Nº. 2 - 2024, ISSN 2668-4748; e-ISSN 2668-4756
Article DOI: https://doi.org/10.35219/mms.2024.2.01

material, highlighting the value of the concept of equivalent carbon as a working tool.

References

[1]. ***, *Welding-Related Expenditures, Investments and Productivity Measurement in U.S. Manufacturing*, Construction, and Mining Industries, 2002.

[2]. Bodea Marius, *Sudare şi procedee conexe*, Editura Utpress Cluj-Napoca, ISBN 978-606-737-143-7, 2016.

[3]. Dorin Dehelean, *Sudarea prin topire*, Editura Sudura, Timişoara, 1997.

[4]. Zgură G., Răileanu D., *Tehnologia sudării prin topire*, Editura Didactică şi Pedagogică, Bucureşti, 1983.

[5]. Echim I., Lupescu I., Nicoară L., *Tehnologii pentru sudarea prin topire a oţelurilor*, Editura Tehnică, Bucureşti, 2002.

[6]. Mircea Burcă, Stelian Negoiţescu, *Sudarea MIG-MAG*, Editura Sudura, Timişoara, 2002.

[7]. Tusz Francisc, *Tratat de sudură*, Editura Sudura, Timişoara, 2003.

[8]. Mihăilescu D., Mihăilescu A., Lupu G., *Tehnologia sudării prin topire - Îndrumar de proiectare*, Editura Fundaţiei Universitare Dunărea de Jos, Galaţi, 2004.

[9]. Dorin Şerban, Eugen Găvan, *Tehnologii de asamblare şi sudare a corpului navei*, Editura Evrika, Brăila, 2001.

[10]. Berinde V., Ánghel I., *Sudarea cu arc electric - Ghid pentru autoinstruirea sudorilor*, Editura Tehnică, Bucureşti, 2010.

[11]. ***, *Cărţi tehnice furnizor echipamente sudare Kemppi*, Finlanda, ESAB – Suedia.

[12]. ***, *Instrucţiuni tehnologice SNDG: I.T.*, nr. 2299, 2300, 2303, 2305, 2339, 2356, 2274 A, 2297.

[13]. Mitelea V. Budau, *Materiale şi tratamente termice pentru structuri sudate*, Editura de Vest, Timişoara, 1992.

[14]. ***, SR EN 10002/1:2002.

[15]. ***, SR EN 10045/1:1993.

[16]. ***, SR EN 1043-1:2004.

[17]. ***, SR EN ISO 156/4-1:2004.