I. UYGUR, B. GULENC

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THE EFFECT OF SHIELDING GAS COMPOSITIONS FOR MIG WELDING PROCESS ON MECHANICAL BEHAVIOR OF LOW CARBON STEEL

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The present study is focused on the mechanical properties of the deposited material which was extracted from welded region. This study explains the effect of the shielding gas composition on tensile behavior, R = - 1 fatigue response and various temperature impact test results of MIG welded low carbon steels. In tensile tests, the strength values are increased with increase of CO_2 content, whereas the ductility is decreased. In the fatigue tests, the fatigue strength and the number of cycles to failure enhanced as the content of CO_2 increased. However, the impact toughness of the filler material is seriously influenced by the content of the shielding gas. An increase in CO_2 content caused significant decrease in toughness values at all temperatures.

Key words: *MIG welding process, shielding pas, low carbon steel, mechanical properties*

Utjecaj sastava zaštitnog plina pri MIG postupku zavarivanja na mehanička svojstva niskougljičnih čelika. Ovaj rad se usredotočio na mehanička svojstva dodatnog materijala uzetog iz zavarenog područja. Rad objašnjava utjecaj sastava zaštitnog plina na vlačnost, R = -1 zamor i rezultate ispitivanja žilavosti na raznim temperaturama niskougljičnih čelika za-varenih metodom MIG. U testovima za ispitivanje vlačne čvrstoće vrijednosti čvrstoće su povećane kao rezultat povećanog sadržaja CO_2, a plastičnost je smanjena. U testovima za ispitivanje zamora povećala se dinamička čvrstoća kao i broj ciklusa prije pucanja zajedno s povećanom količinom CO_2. Međutim, žilavost materijala za dodavanje jako ovisi o zaštitnom plinu. Povećanje količine CO_2 značajno smanjuje žilavost na svim temperaturama.

Ključne riječi: *MIG postupak zavarivanja, zaštitni plin, nisko ugljični čelik, mehanička svojstva*

INTRODUCTION

In MIG welding process, the electric potential established between the electrode and workpiece causes current flow, which generates thermal energy in the partially ionised gas. The current also creates the surrounding magnetic field, which interacts with the diverging current field to induce an electromagnetic force that accelerates the plasma, generating a flow towards and across the workpiece surface. Intense heat generation and high plasma velocities are created with a rapid transfer of heat into the molten weld pool. In the MIG process, heat is generated both by resistive heating and by heat transfer from the are current. The tip of the wire is molten. The molten droplets are formed and driven into and through the plasma jet into the weld pool. The MIG process can be operated under a variety of weld metal transfer modes. Each mode of metal transfer has benefits and limitations and is normally selected on the base of the requirements of a particular welding job. Each transfer mode can be operated by one of several shielding gases. The primary function of the shielding gas was to protect molten and heated metal from the deleterious effect of the surrounding air and to provide suitable atmosphere for the arc. Since air comes in contact with the molten or heated metal, the oxygen in the air will oxidize the material. The nitrogen and the sulphur might cause porosity or brittleness in the welding material. These defects act as the stress concentrators and diminish some mechanical properties of the welding materials. Recently, MIG welding process, with either solid or metal cored welding Wires, have gained popu1arity among the different types of welding, because high-quality and economical welds can be obtained by MIG welding. The quality, efficiency and over all operating acceptance of welding operation are strongly dependent on the shielding gas, since it dominates the mode of the metal transfer. During welding, the shielding gas also interacts with the welding wire to produce the strength, toughness and corrosion resistance of the some particular welding deposits. Studies have

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I. Uygur, Faculty of Technical Education, Abant Izzet Baysal University, Beciyorukler, Turkey, B. Gulenc, Faculty of Technical Education, Gazi University, Ankara, Turkey

shown that the increase in oxygen and hydrogen in the weld, increases its strength, but, on the opposite the toughness is decreased [1]. In MIG welding a great part is played by the type of the shielding gas used, since it affects the arc shape, the material transfer mode and the energy (temperature) distribution in the arc. At present, the mixture of two, three or even more different gases is used to protect the arc and the molten pool. The most frequently used gases are CO_2 and Ar in various mixtures. Argon is an inert gas. This means that it does not oxidize and that it has no effect on the chemical composition of the welding metal. However, pure argon causes the unstable arc. Therefore, an oxidizing gas component is used to stabilize the arc and to ensure a smooth metal transfer during welding. This component may be either CO_2 or O_2 or a combination of these two gases. The mechanical properties of the welding metal are strongly influenced by the shielding gas [2]. The lower the CO_2 or O_2 content of the shielding gas, the less inclusions of oxides are formed. The microstructure also becomes more finely grained which benefits the impact strength. Lower CO_2 and O_2 content give a lower burning of alloying elements (Si, Mn) which results in higher yield and ultimate tensile stress (UTS). Also the fatigue properties of the CO_2 gas shielded welding is better than other shielding mixtures [2]. Fatigue strength may also be influenced by the number of the oxide inclusions if the weld is grinded or polished. The oxide can act as the starting point for cracks. The higher the CO_2 or O_2 content in the shielding gas, the more oxide inclusions will he found in the welding material.

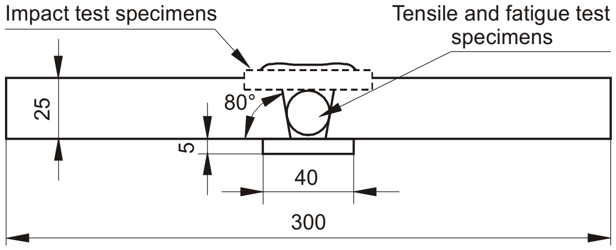

Figure 1. **The dimensions of the welded material and extracted samples**
Slika 1. **Dimenzije zavarenog materijala i mjesta uzimanja uzoraka**

In the present study, a low carbon steel was welded by MIG process. The filler metal of the similar chemical composition to the parent material was used for welding. The specimens used in the investigation were extracted from the welding region (i.e. only deposited metal). This study aims to examine how different shielding gases influence mechanical properties.

EXPERIMENTAL PROCEDURES

The specimens used in the investigation were extracted from a welded joint of low carbon steel. A schematic diagram of the test plate is shown in Figure 1. The configuration of joint groove was V-shaped and welding was completed in 13 multipass using Bohler^{TM} SG2 wires. A 25 mm (*t*) x 160 mm (*w*) x 430 mm (*l*) base metal plate of AISI type 1020 plain low-carbon steel was used for the flat position welding. Cylindrical tensile specimens and square impact specimens were machined from deposited metal. Cylindrical tensile specimens were taken parallel to the welding direction at a fixed distance from welding center as shown in Figure 1. Square impact specimens were taken perpendicular to the welding direction, this is also shown in the same Figure. Various shapes of the specimens which are used in the present study and their dimensions are given in Figure 2. The chemical composition of the filler material and the parent metal are given in Table 1. and Table 2. After finishing for final shape and dimensions, the specimens were annealed at 650 °C for 30 minutes. The surface of each specimen was polished with SiC paper. The Woller type testing machine was used to load specimens for fatigue tests. For cyclic loading, load ratio was R = - 1 with a frequency range of 20 - 25 Hz were employed. Tensile and fatigue tests were performed at room temperature and three specimens were used for each condition. Impact testing of the Charpy specimens was per-

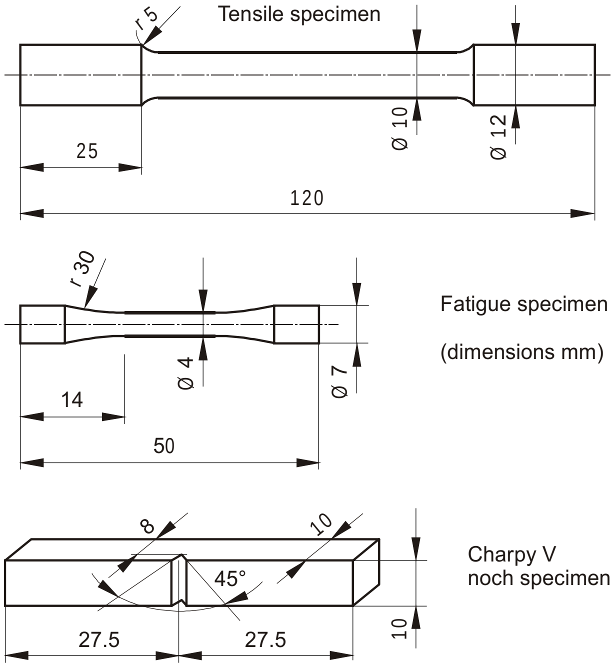

Figure 2. **Various types of the specimens and their dimensions**
Slika 2. **Razni tipovi uzoraka i njihove dimenzije**

Table 1. **Chemical composition of the base material**
Tablica 1. **Kemijski sastav osnovnog materijala**

Element	C	Si	Mn	P	S
Weight [%]	0.144	0.221	0.514	0.0186	0.0437

Table 2. **Chemical composition of the wire**
Tablica 2. **Kemijski sastav žice**

Element	C	Si	Mn	P	S
Weight [%]	0.068	0.763	1.410	0.020	0.014
Element	Al	Ni	Cr	Cu	Mo
Weight [%]	0.002	0.041	0.031	0.026	0.002

formed at temperature s ranging from - 60 to 20 °C at an impact velocity of 5.25 ms^{-1} using a tub capacity of 45 kN. The shielding gas mixtures are given in Table 3. These mixtures are commonly used for many industrial applications. The welds were carried out in the fiat position using the ESAB™ 400 type of semi automatic welding machine. During welding, welding parameters, gas flow, and welding speed were measured. The welding machine characteristics and other parameters are given in Table 4.

Table 3. **Mixture of theshielding gases**
Tablica 3. **Smjesa zaštitnog plina**

No	1	2	3	4	5	6	7
Argon [%]	-	100	95	85	70	91	83
CO_2 [%]	100	-	5	15	30	5	13
O_2 [%]	-	-	-	-	-	4	4

Table 4. **Welding parameters**
Tablica 4. **Parametri zavarivanja**

Current [A]	Voltage [V]	Welding speed [cm/dk]	Passes [-]	Wire diameter [mm]	Nozzle diameter [mm]	Gas flux [lt/dk]	Wire lenght [mm]
280 ± 10	28 ± 2	24	13	1.2	1.4	18	25

RESULTS AND DISCUSSION

Tensile properties

Figure 3. shows the effects of gas type on the tensile response of the deposited metal. It can be seen from Figure that both the yield strength (σ_y) and UTS are higher, under the pure argon shielding environment compared with the pure CO_2. Similar improvement can also be seen in ductility. The composition of the shielding gas effect on the tensile response are shown in Figure 4. and 5. These Figures illustrate that the reduction in CO_2 composition causes slight decrease in the ductility of the deposited material. However, an increase in CO_2 content, causes improvement in the tensile strength values. Ar is obtained from the atmosphere. Being 1.38 times heavier than the air, it provides a very efficient and stable protection of the arc and the molten pool. Owing to its low ionization energy, arc ignition under protection of argon is very reliable. Its burning is very stable, also it is more suitable for longer welding arcs [3]. Thus an increase in Ar content can provide better condition for the molten pool which is less affected by the hazardous gases, such as oxygen (O_2), nitrogen (N) and hydrogen (H). It is observed that spatters are generated in the flat position with all the gas mixtures. Spatter rates increased with increasing CO_2 and O_2 content. Pure CO_2 gives coarser spatter than argon environment. A CO_2 and O_2 are oxidizing gases. They are very active at high temperature, therefore their chemical effect on the filler metal or base plate is strong. As spatter comes from the filler metal, more spatter will also lower

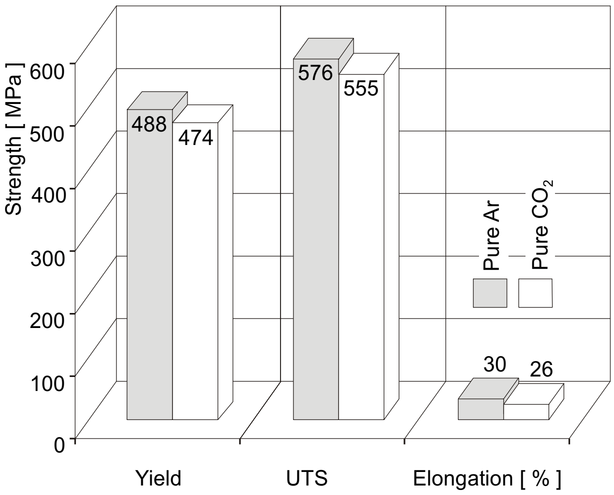

Figure 3. **The effect of the gas type on the tensile response of the deposited metal**
Slika 3. **Utjecaj vrste plina na vlačnu čvrstoću dodatnog metala**

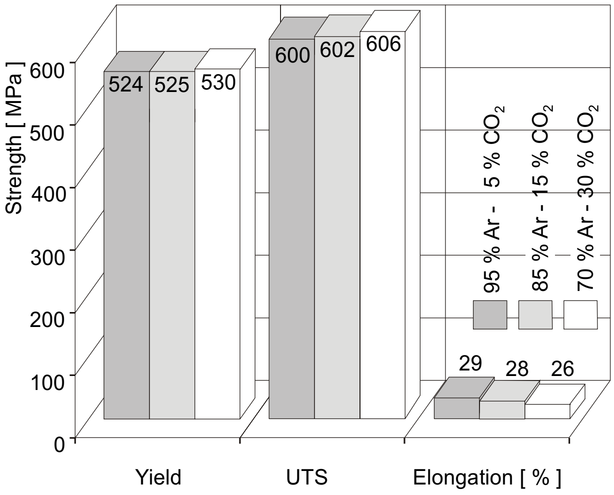

Figure 4. **The effect of the shielding gas composition on the tensile response of the deposited metal**
Slika 4. **Utjecaj sastava zaštitnog plina na vlačnu čvrstoću dodatnog metala**

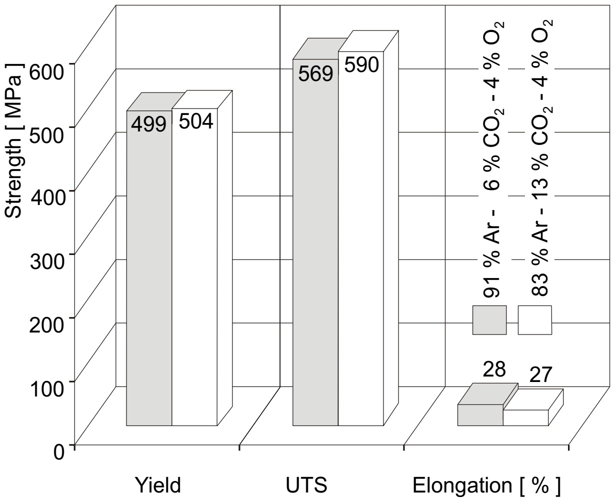

Figure 5. **The effect of the shielding gas composition on the tensile response of the deposited metal**

Slika 5. **Utjecaj sastava zaštitnog plina na vlačnu čvrstoću dodatnog metala**

the electrode efficiency and increase the cost for the filler metal. Studies have shown that the increase in O_2, CO_2 and H in the welding, enhanced the tensile strength of the titanium alloys [1-4]. Similarly in the present study, the tensile properties of the materials are influenced by the shielding gas content. The lower the CO_2 or O_2 content of the shielding gas, the cleaner the molten pool. This means less inclusions of the oxides. The microstructure also becomes more finely grained which benefits in ductility and tensile strength.

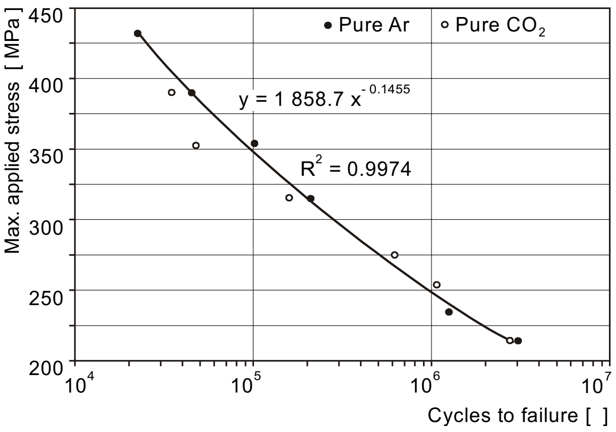

Figure 6. **The effect of the gas type on the fatigue response of the deposited metal**

Slika 6. **Utjecaj vrste plina na zamor dodatnog metala**

Fatigue properties

In the fatigue design, the most useful information is the applied maximum stress versus number of cycles, that is S-N curve. S-N curve is conventionally obtained by testing a group of standard specimens without cracks at different stress levels until any failure occurs. The effect of the gas type on S-N curves are illustrated in Figure 6. From thise Figure, it is clearly seen that, there is almost no significant differences in low cycle and high cycle fatigue regime and all test results lie within a relatively tight scatter band so that both environments may be presented by one common curve. The fatigue properties of welding can also be affected by the shielding gas. Fatigue strength is mostly dependent on the welding geometry. Since welding with argon creates a weld with a smoother transition between the weld head and base metal, thus, the fatigue properties are slightly better than for welds shielded with CO_2. Also the fatigue properties are influenced by the number of oxide inclusions. The oxide can act as starting points for cracks. The higher the CO_2 or O_2 content in the shielding gas, the more oxide inclusions will be formed in the welding metal. However, increased tensile strength values in 70 % Ar - 30 % CO_2 shielding gas improved the fatigue properties of filler material compared with other shielding media. Moreover, the tensile properties of the filler material are slightly better than CO_2 environment compared with argon environment (Figure 3.). It is well known that tensile properties are one of the significant parameters which affect the fatigue response of the materials. These may cause slight enhancement in fatigue life response in argon environment compared with CO_2. Comparative S-N curves for the increasing CO_2 content in argon environments are displayed in Figure 7. and 8. Again, an increase in CO_2 content in the shielding gases have caused superior fatigue lives. These are attributed to the relatively different microstructure and tensile responses of the filler material in various shielding gas environments (Figure 4., 5.). From the S-N curves, the common lines can be drawn for each figure and the following regression formula can be obtained:

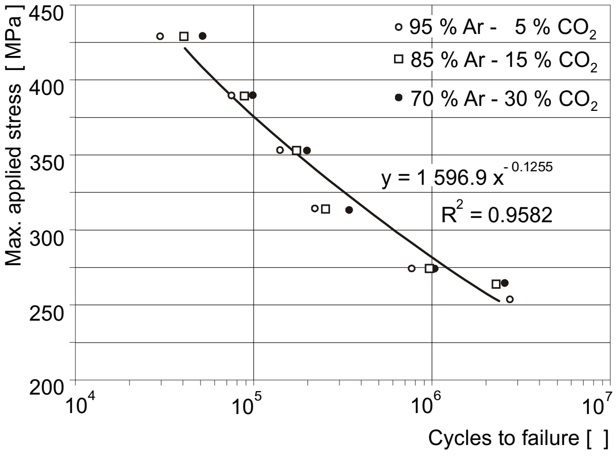

Figure 7. **The effect of the shielding gas composition on the fatigue response of the deposited metal**

Slika 7. **Utjecaj sastava zaštitnog plina na zamor dodatnog metala**

$$\sigma_{max} = 1596 - 1858 \cdot (N_f)^{-0.1255 - 0.1455} \qquad (1)$$

where:

σ_{max} is maximum applied stress,
N_f is number cycles to failure.

The lines drawn in figures represent equation (1). Note that the lines have positive slopes. This indicates that when the maximum applied stress under fatigue loading decreases, the number of cycles to failure increase.

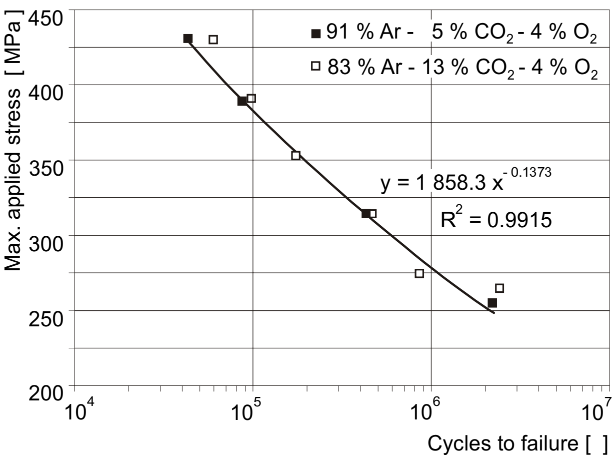

Figure 8. **The effect of the shielding gas composition on the fatigue response of the deposited metal**
Slika 8. **Utjecaj sastava zaštitnog plina na zamor dodatnog metala**

Impact properties

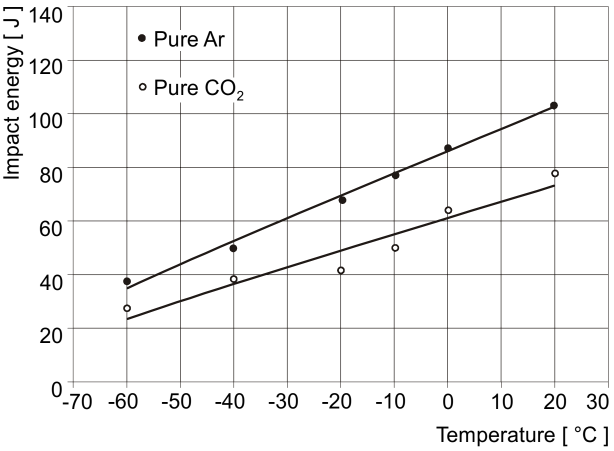

Figure 9. **The effect of the gas type on impact toughness of the deposited metal**
Slika 9. **Utjecaj vrste plina na žilavost dodatnog metala**

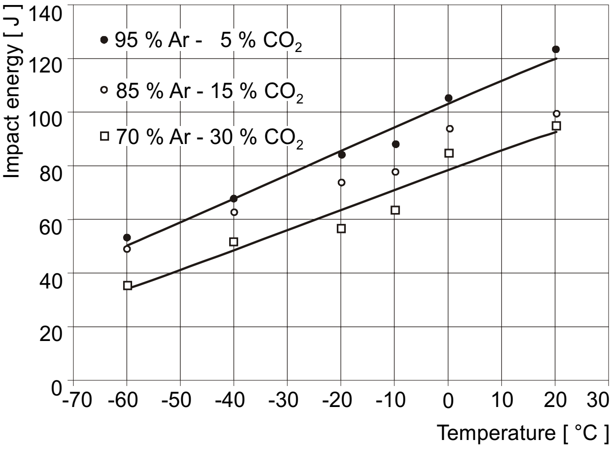

Figure 10. **The effect of the shielding gas composition on impact toughness of the deposited metal**
Slika 10. **Utjecaj sastava zaštitnog plina na žilavost dodatnog metala**

The observation of the structure on a microscopic scale showed that the austenitic and ferrite phases were found in all deposited metals. Both dendrictic and lathy ferrites bawe been observed. The dendrictic ferrite morphology results from perlite solidification. Ferrite in lathy morphology results from the dissolution of ferrite during cooling [5]. The present study shows that the ferrite volume fraction decreases by increasing the amount of CO_2 in the Ar-CO_2 mixtures. The impact energy versus testing temperature for the deposited metal in Ar and CO_2 environment has been plotted in Figure 9. Also the effect of CO_2 and O_2 in the mixture of shielding gas and their result on impact toughness values are displayed in Figure 10. and 11. They show that, the impact energy decreases with decreasing testing temperature in all conditions. It is also clearly seen that the difference of the energy is quite large at high testing temperatures, while it is much less at low testing temperatures. This phenomena can he explained by dimple rapture at high temperatures and cleavage brittle fracture at the cryogenic temperatures [6]. In the present study it is also observed that the fracture surface morphology is dimple rupture. The dimples are mainly associated with the impurity particles (inclusions), which are generally round and have various sizes. The results of EDAX analysis indicate that the inclusions contained silicon, chromium, iron and manganese. It means that the inclusions were mainly silicon oxides and manganese oxides. Inclusions which act as crack sites will degrade the notch toughness property. The number of the oxides can be determined by the oxygen potential and it increases with increasing O_2 content. The O_2 potential of the shielding gas is estimated by using the formula [7]:

$$O_p = O_2 + \mu \cdot CO_2 \qquad (2)$$

Where μ is oxidizing factor and it is taken as 0.5 in the present study [7]. The influence of the oxygen potential on notch toughness at various temperatures is shown in

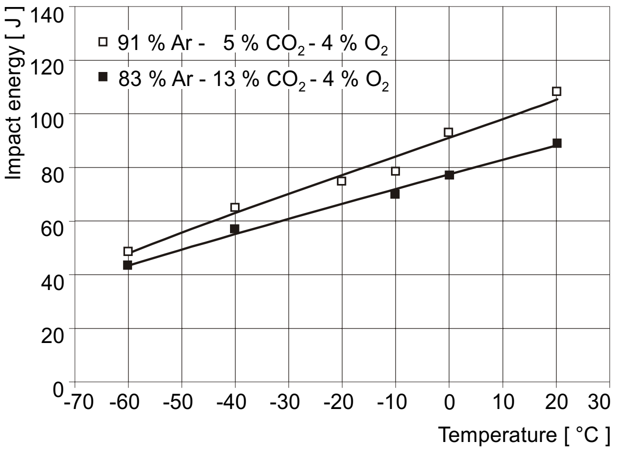

Figure 11. **The effect of the shielding gas composition on impact toughness of the deposited metal**

Slika 11. **Utjecaj sastava zaštitnog plina na žilavost dodatnog metala**

Figure 12. It is obvious that the notch toughness drops as the O_2 potential increases at high testing temperature, while it is insensitive to oxygen potential at low testing temperatures. Thus, the notch toughness is strongly dependent on the oxygen potential. The higher oxygen content results in a degradation of notch toughness. It is assumed that the impact energy is decreased by increasing CO_2 content of the Ar-CO_2-O_2 mixtures with various CO_2 content percentages from 5 to 30 %. The 70 % Ar - 30 % CO_2 mixture welded material has the lowest impact energy since it bas the highest oxygen potential. It is also evident from the Figure 3., 4., 5. that the increase in the CO_2 content results in significant amount of decrease in the ductility.

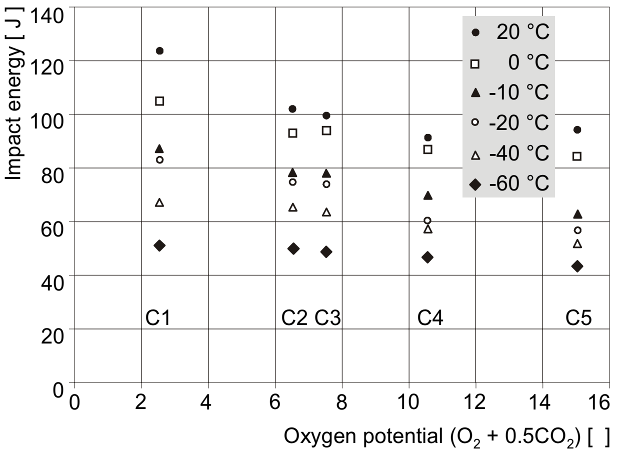

Figure 12. **The influence of the Oxygen potential as notch toughness at various temperatures. (Cl = 95 % Ar - 5 % CO_2; C2 = 85 % Ar - 15 % CO_2; C3 = 70 % Ar - 30 % CO_2; C4 = 91 % Ar - 5 % CO_2 - 4 % O_2; C5 = 83 % Ar - 13 % CO_2 - 4 % O_2)**

Slika 12. **Utjecaj potencijala kisika na žilavost pri različitim temperaturama. (Cl = 95 % Ar - 5 % CO_2; C2 = 85 % Ar - 15 % CO_2; C3 = 70 % Ar - 30 % CO_2; C4 = 91 % Ar - 5 % CO_2 - 4 % O_2; C5 = 83 % Ar - 13 % CO_2 - 4 % O_2)**

CONCLUSIONS

On the basis of the practical studies accomplished and the results obtained from the influence of CO_2 and O_2 in various shielding media on the tensile, fatigue and impact properties of the law carbon steel, the following conclusions may be drawn:

- the tensile properties of the filler material is affected by the shielding gas media. An increase in CO_2 content causes an improvement in the tensile strength whereas the ductility is decreased,
- the impact tests at room temperature revealed that the impact toughness of Argon media is the highest, the 70 % Ar - 30 % CO_2 mixture welded material is the lowest impact energy due to the high level of the oxygen potential,
- in the fatigue tests, the S-N curves are quite similar in argon and CO_2 media, however they are shifted down and the fatigue strength is decreased as the CO_2 content is increased in the shielding gas. This may explain an increase in CO_2 content that might cause more inclusions which were mainly crack initiation points and cause early failure of the specimen,
- the present study is focused on' three different gases, the effect of the helium and the hydrogen in the shielding media may he investigated,
- mechanical properties may be enhanced as the Ar composition is increased in the shielding gas media.

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