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Proposal of welding methods in terms of the amount of oxygen

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ABSTRACT

Purpose: Purpose of this paper is to remind proposals for welding processes classification in terms of oxygen in WMD (weld metal deposit), and confirmation of that concept after further 12 years of new research and results.

Design/methodology/approach: Welds were obtained with various oxygen content. There were investigated properties of WMD, especially metallographic structure, toughness and fatigue strength of welds with various oxygen amount. The connection between the properties of welds with the content of oxygen in WMD were carried out.

Findings: Demonstrated that oxygen content in WMD has an important influence on metallographic structure, especially on the percentage of acicular ferrite in weld. The preferred structure improves the mechanical properties of welded joints.

Research limitations: The research results indicate that oxygen content in steel welds should be limited. Subsequent researchers could find more precisely the most beneficial oxygen amount in the welds in terms of the amount of acicular ferrite in welds.

Practical limitations: To obtain welds with the best properties should be chosen suggested low-oxygen process. It is therefore suggestion to use much more basic electrodes than rutile for steel welding.

Originality/value: Proposal of welding methods in terms of oxygen content in welds was given 12 years ago, however still it is not very popular. New researches and results could prove that it is very important and original proposal.

Keywords: Welding; Oxygen; Classification; Acicular ferrite; Impact properties; N-S curves

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Classification of welding processes of low-carbon and low-alloy steel in terms of the amount of oxygen was firstly suggested on ISOPE Conference in Brest in 1999 [1]. Since then, a new research has confirmed the validity of this concept [2,3,4]. Different methods of arc welding processes were tested, such as welding with coated electrodes (especially basic and rutile electrodes), shielded arc welding process MIG/MAG (various wires and shielded gases), submerged arc welding process (various wires and fluxes). The amount of oxygen and the percentage of acicular ferrite of metal weld deposits were mainly analysed and the impact toughness of it. Metallographic structures and fractography tests of weld metal deposit were carried out by putting attention to non-metallic inclusions presence in deposit. N-S curves were done for typical deposits with varied amount of oxygen in WMD. Additional inclusions observation and measurements were prepared using a scanning electron microscope equipped with an energy-dispersive X-ray spectrometer. Effect of oxygen in weld is not the same like in steel [2-8]. Amount of oxygen in WMD is normally ten times higher in comparison with steel. Sometimes it could be more than 1000 ppm oxygen in WMD, that corresponds with 0.3% of oxide inclusions in metal weld deposit. It is also observed that oxygen amount in WMD could be lower than 200 ppm. Both values are not beneficial for good toughness properties [3,5]. It was observed that oxide inclusions in steel metal weld deposit have main influence on the transformation austenite→acicular ferrite (AF). Acicular ferrite is observed only in steel welds. The quality, quantity, type and size of inclusions determines the formation of acicular ferrite. Especially two non-metallic oxide inclusions TiO and $MnAl_2O_4$ have an important influence on the formation of acicular ferrite. Those oxide inclusions have a FCC lattice structure, and it could possibly be compatible with the BCC lattice structure of ferrite that is beneficial for the transformation austenite→acicular ferrite. Also the size of inclusions could have an influence on forming acicular ferrite and thereby resulting in obtaining better impact toughness properties. Thus the toughness of the metal weld deposits is affected by the amount of oxygen and the amount of acicular ferrite in the metal weld deposits. The toughness of the metal weld deposits is also affected by morphology and density of inclusions [5,6]. This is the reason, why the amount of oxygen could be treated as the important factor on metallographic structures and impact properties of weld metal deposit. In metallurgy of steel, it is treated that the lowest amount of oxygen gives best toughness properties of steel. In metallurgy of welding it is suggested that oxygen in deposits should be in range (200-500 ppm). The amount of oxygen in weld metal deposit depends mainly on filler materials, shielded gases, and methods of welding [2].

In analogy to the classification of weld metal deposits, and arc welding processes of low-carbon and low-alloy steel, in terms of the amount of hydrogen in metal weld deposits, a similar classification was given in terms of the amount of oxygen. The studies were mainly made on the classification of metal weld deposits and arc welding processes of low carbon and low alloy steel in terms of the amount of oxygen in metal weld deposits on the following processes: low-oxygen processes, medium-oxygen processes, high-oxygen processes. Classifications of welding processes give important hints for engineers [9-15].

2. Experimental procedure

Three main methods of welding: Submerged Arc Welding (SAW) processes, Shielded Metal-Arc Welding (SMAW) process, Gas Shielded-Arc Welding (GSAW) process were chosen to assess the effect of oxygen on mechanical properties of deposited metal electrodes.

In order to analyse Gas Shielded-Arc Welding process, different electrodes were prepared in experimental way:

- low alloy steel electrodes (acid, rutile and basic coatings)

The electrodes contained coatings, constant or variable proportions of standard components in powder form. The principal composition was modified by separate additions of oxidiser (Fe_3O_4) and deoxidisers (FeTi, FeSi and Al in powder form) in electrode coatings. The principal diameter of the electrodes was 4 mm. The standard current was 180A, and the arc voltage was 22 V. As a result after welding, the amount of oxygen in low-carbon and low-alloy steel metal weld deposits ranged between 200 and 1100 ppm. Various fluxes and wires were tested in submerged arc welding process. A variable chemical composition of metal weld deposits was resulted because of the variable oxidisers (Al and Ti) and deoxidisers. Filler materials (wires and fluxes) were prepared in experimental ways, and also typical industrial filler materials were tested in order to assess the effect of oxygen on weld deposits. In order to analyse the process of the influence of oxygen on mechanical properties of MIG/MAG deposits, various wires were taken and various shielded gases (CO_2, Ar) and gas mixtures (80% Ar–20% CO_2) and 98.5% Ar–1.5% O_2). The deoxidisers (Al, Si, Mn) in wires and oxidising gazes (O_2 and CO_2) allowed to get metal weld deposits with variable amount of oxygen contained. There were tested mainly two typical wires:

- wire 1.5% Mn / 0.8% Si,
- wire 1.5% Mn / 0.8% Si + 0.12% Al.

The principal diameter of the wires for the GSAW process was 1.2 and 1.6 mm.

Using those mentioned methods of welding (SAW, SMAW, GSAW processes) it was possible to obtain a typical structures, and chemical composition in all tested weld metal deposits.

A typical low alloy low carbon weld metal deposits after welding had the following chemical composition (Table 1):

Table 1.
A typical low alloy low carbon weld metal deposits after welding

C	bellow 0.06%	Ti	up to 0.02%
Mn	up to 1.4%	P	max 0.013%
Si	up to 0.4%	S	max 0.013%
Al	up to 0.02%	N	max 80 ppm (at.)
		O	200 to 1100 ppm (at.)

For each of the following deposits a chemical analysis, micrograph tests, and Charpy V-notch impact toughness test was carried out. The main Charpy tests were done mainly at +20°C using 5 specimens from each weld metal. Charpy V-notch impact toughness tests of the selected weld metal at lower temperatures were also done with 5 specimens.

3. Results and discussion

On the bases of the results shown in Figures 1 and 2, the role of oxygen in the SMAW process was precisely analysed.

In Figure 1 it is well shown that oxygen has important influence on impact toughness properties of weld metal deposit. Figure 2 shows relationship between metal structure of deposits and impact toughness of deposits. Those deposits were prepared with variable parameters of the process in order to obtain variable amounts of acicular ferrite.

Fractography tests indicates more that amount of acicular ferrite in WMD are connected with the size of inclusions (and their chemical composition), Figures 3, 4.

The quality, quantity, type and size of inclusions determines the formation of acicular ferrite. It is possible to deduce that inclusions are a heterogeneous nature and that the following oxides TiO_2, TiO, FeO, SiO_2, MnO, CaO, MgO, $MnAl_2O_4$, Al_2O_3 are dominant. Also the size of inclusions should have an influence on forming acicular ferrite and thereby resulting in obtaining better impact toughness properties. Thus the toughness of the metal weld deposits is affected by the amount of oxygen and the amount of acicular ferrite in the metal weld deposits. The relationship between chemical composition of wires and shielded gas mixtures on the amount of oxygen in weld metal deposits are presented in Table 2.

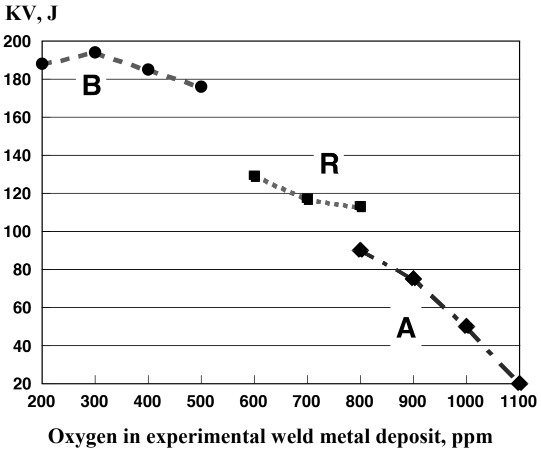

Fig. 1. Impact toughness (at 20°C) of deposits with variable amount of oxygen. Deposits were experimented by: acid electrodes (EA), rutile electrodes (ER) and basic electrodes (EB) [1,2]

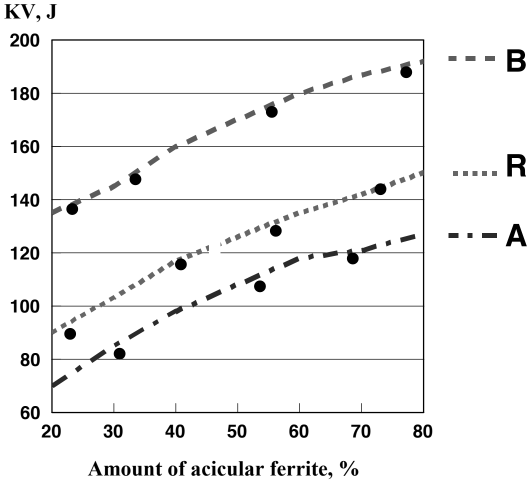

Fig. 2. A relationship between the percentage of acicular ferrite in WMD, and impact toughness of deposits (EA acid electrodes, ER rutile electrodes, EB basic electrodes) [1,2]

Impact toughness of weld metal deposit in terms of the amount of oxygen is shown in Figure 5.

On the bases of the results shown in Table 3 the role of oxygen in submerged arc welding process was analysed.

In Figure 5 it is shown that impact toughness of metal weld deposits decreased in terms of the increscent of the amount of oxygen in tested deposits of all temperatures.

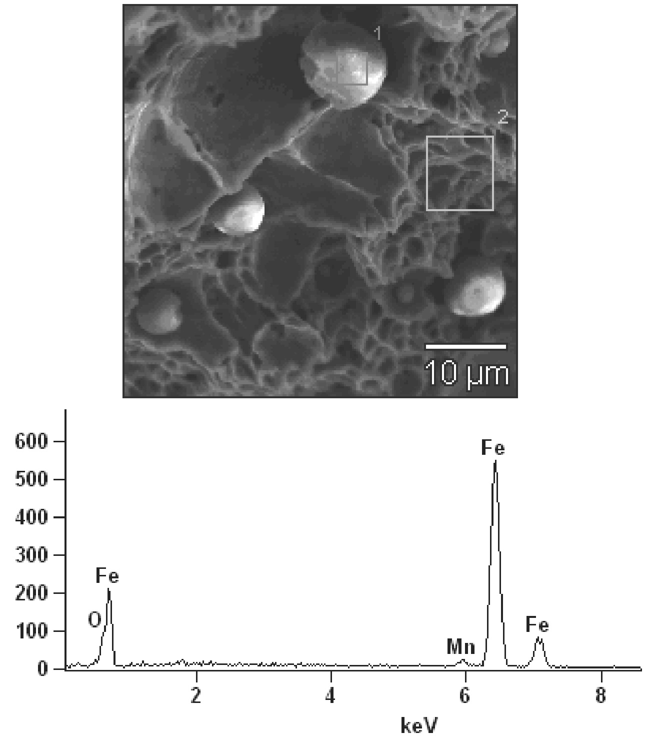

Fig. 3. Fractography of rutile WMD (big size of inclusions) with EDS chemical analysis of the inclusion

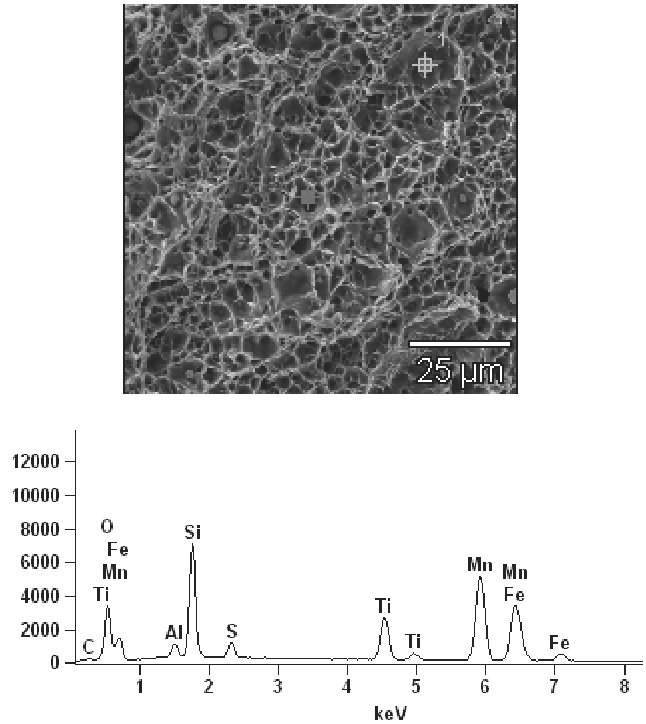

Fig. 4. Fractography of basic WMD (small size of inclusions) with EDS chemical analysis of the inclusion

Table 2.
Amount of oxygen in weld metal deposit in terms of chemical composition

of wires and gas mixtures	oxygen in metal weld deposit, ppm	oxygen in metal weld deposit, ppm	oxygen in metal weld deposit, ppm	oxygen in metal weld deposit, ppm
wire	shielded gas: CO_2	shielded gas: 80% Ar / 20% CO_2	shielded gas: 98.5% Ar / 1.5% O_2	shielded gas: Ar
1.5Mn-0.8Si	560	480	420	380
1.5Mn-0.8SiAlTi	505	460	370	325

Table 3.
Amount of oxygen in steel weld metal deposit made by various filler materials

Main chemical composition of wire	Basic Flux	Agglomerating flux;
	Amount of oxygen in steel metal weld deposit, ppm	Amount of oxygen in steel metal weld deposit, ppm
0.5% Mn,	670	-
0.5% Mn, 0.12% Si, 0.1% Al	510	-
1.2% Mn, 0.3% Si	-	480
1.2% Mn, 0.25% Si, 0.14% Al	-	360

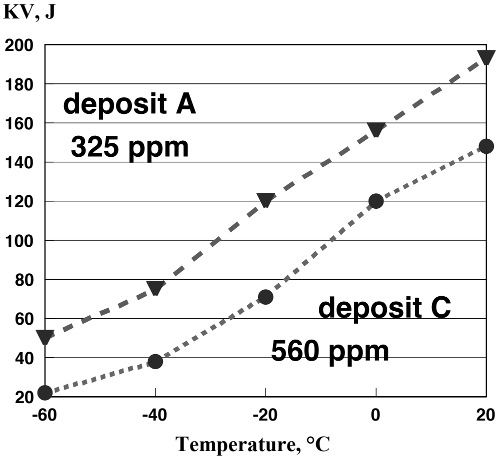

Fig. 5. Impact toughness of metal weld deposits with the lowest and highest amount of oxygen in tested deposits. Deposit A: 1,5% Mn, 0,8% Si + Al + Ti (shielded gas: Ar), Deposit C: 1,5% Mn, 0,8% Si (shielded gas: CO_2) [1,2]

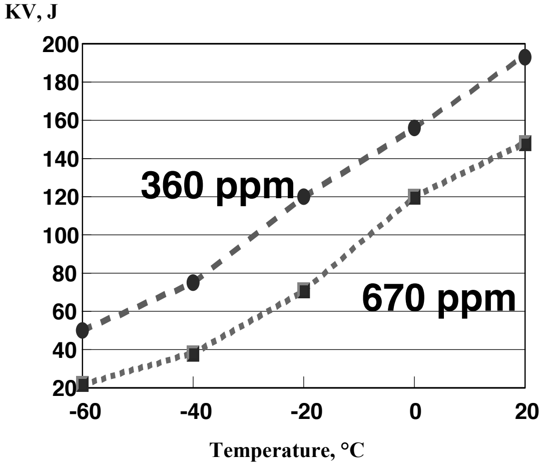

Fig. 6. Impact toughness of SAW low alloy weld metal deposit with the lowest and highest amount of oxygen in obtained deposits [1,2]

Impact toughness of metal weld deposits depends on the amount of oxygen in obtained deposits. In Figure 6 is presented toughness properties of metal weld deposits for the lowest and highest amount of oxygen in obtained deposits.

Also in the last tested welding process (SAW), it was possible to deduce that impact toughness of metal weld deposit is affected by the amount of oxygen. Decrescent of impact toughness of low alloy metal weld deposit in terms of the increscent of the amount of oxygen in deposits was observed in all tested temperatures. Last part of the project was to compare N-S curves of typical deposits of basic and rutile electrodes giving various amount of oxygen in welds after process. Fatigue tests were generated for two deposits: with low amount of oxygen on the level of 350 ppm (typical for basic electrodes), and 800 ppm (typical for rutile electrodes). The samples and tests were done according to Polish Standards (Figures 7,8).

Looking for the S-N curve for the deposit to make an estimate of its fatigue life it easy to deduce, that low amount of O (in basic WMD having 350 ppm O) could be treated as beneficial (in comparison with rutile WMD having 800 ppm O), Figure 6.

It was able to compare the fatigue values for deposits having various amount of oxygen. Also in this case deposits having lower amount of oxygen could be treated as more beneficial.

4. Conclusions

Examination of the influence of amounts of oxygen on alloy steel weld metal deposit using variable methods of welding allows to indicate again the classification of filler materials and arc welding processes in terms of the amount of oxygen in metal weld deposits.

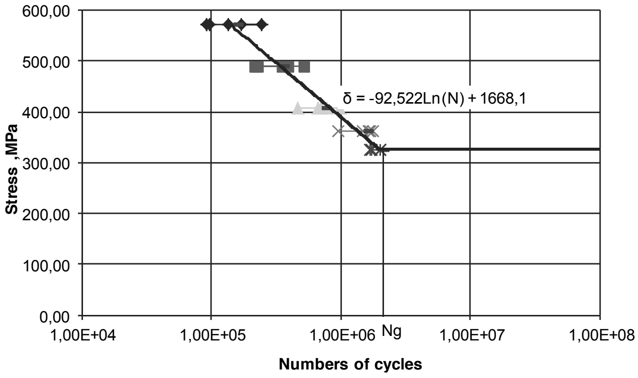

Fig. 7. S-N Fatigue properties for basic WMD with 350 ppm O

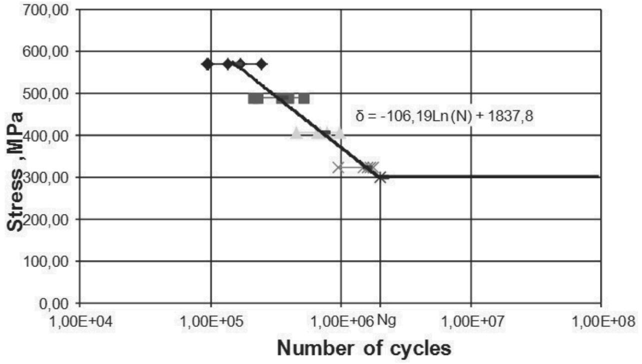

Fig. 8. S-N Fatigue properties for rutile WMD with 800 ppm O

1. Proposal of the classification for electrodes and SMAW welding processes:
    - low-oxygen electrodes/process (amount of oxygen in metal weld deposit is in range 250-450 ppm),
    - medium-oxygen electrodes/process (amount of oxygen in metal weld deposit is in range 450-650 ppm),
    - high-oxygen electrodes/process (amount of oxygen in metal weld deposit is greater than 650 ppm).
2. Proposal of the classification for electrodes and GSAW welding processes:
    - low-oxygen filler materials/process (amount of oxygen in metal weld deposit is less than 350 ppm),
    - medium-oxygen filler materials /process (amount of oxygen in metal weld deposit is in range 350-500 ppm),
    - high-oxygen filler materials /process (amount of oxygen in metal weld deposit is greater than 500 ppm).
3. Proposal of the classification for electrodes and SAW welding processes:
    - low-oxygen filler materials /process (amount of oxygen in metal weld deposit is below 450 ppm),
    - medium-oxygen filler materials /process (amount of oxygen in metal weld deposit is in range 450-650 ppm),
    - high-oxygen filler materials /process (amount of oxygen in metal weld deposit is greater than 650 ppm).

References

[1] T. Węgrzyn, The Classification of Metal Weld Deposits in Terms of the Amount of Oxygen, Proceedings of the Conference of International Society of Offshore and Polar Engineers ISOPE´99, Brest, France 1999, International Society of Offshore and Polar Engineers, vol. IV, Cupertino - California, USA, 1999, 212-216.

[2] T. Węgrzyn, Oxygen and nitrogen in metal weld deposits using arc welding processes, Publishing House of the Warsaw University of Technology, Warsaw, 1999, 1-140.

[3] G.M. Evans, The effect of micro-alloying elements on the microstructure and properties of ferritic all-weld metal deposits, IIW Doc II-A-855-92.

[4] T. Węgrzyn, Oxygen and nitrogen in low carbon basic electrode weld metal deposits, IIW-Comission II: Arc Welding, Sub-Commission II A: The Metallurgy of weld metal, 1992, Doc.II-A-1181-92.

[5] G. Biswas, G.J. Kulkarni, Nucleation of Proetectoid Ferrite at Manganese-Sulphide Inclusion Sites in HY-80 Steel, Proceedings of the International Offshore and Polar Engineering Conference, Honolulu, 1997.

[6] S. St-Laurent, G. L'Esperance, Effects of Chemistry and size distribution of inclusions on the nucleation of acicular ferrite of C-Mn steel shielded-metal-arc-welding weldments, IIW Doc II-A-900-93, 1993.

[7] T. Węgrzyn, R. Burdzik, Effect of Mn and Mo on the quality of trucks steel supporting structures, Journal of Achievements in Material and Manufacturing Engineering 43/1 (2010) 276-279.

[8] T. Węgrzyn, R. Szopa, M. Miros, Non-metallic inclusions in the weld metal deposit of shielded electrodes used for welding of low-carbon and low-alloy steel, Welding International 23 (2009) 54-59.

[9] A. Lis, J. Lis, C. Kolan, M. Knapiński, Effect of strain rate on hot ductility of C-Mn-B steel, Journal of Achievements in Material and Manufacturing Engineering 41 (2010) 26-32.

[10] J. Dobrzański, M. Sroka, Automatic classification of the 13CrMo4-5 steel worked in creep conditions, Journal of Achievements in Material and Manufacturing Engineering 29/2 (2008) 147-150.

[11] N. Wolańska, A. Lis, J. Lis, Investigation of C-Mn-B Steel After Hot Deformation, Archives of Materials Science and Engineering 28/2 (2007) 119-125.

[12] J. Ćwiek, Prevension methods against hydrogen degradation of steel, Journal of Achievements in Material and Manufacturing Engineering 43/1 (2010) 214-221.

[13] J. Ćwiek, Hydrogen degradation of high-strength steels, Journal of Achievements in Material and Manufacturing Engineering 37/2 (2009) 193-212.

[14] J. Ćwiek, Hydrogen degradation of high strength weldable steels, Journal of Achievements in Material and Manufacturing Engineering 20 (2007) 223-226.

[15] L.A. Dobrzański, E. Jonda, K. Lukaszkowicz, A. Kriz, Structure and tribological behavior of surface layer of laser modified X40CrMoV5-1 steel, Journal of Achievements in Material and Manufacturing Engineering 18 (2006) 343-346.