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THE COMBINED INFLUENCE OF MOLYBDENUM AND NICKEL IN STEEL WELDS

Weld metal deposit (WMD) was carried out for standard MMA welding process. This welding method is still promising mainly due to the high amount of AF (acicular ferrite) and low amount of MAC (self-tempered martensite, retained austenite, carbide) phases in WMD. That structure corresponds with good impact toughness of welds at low temperature. Separate effect of these elements on the mechanical properties of welds is well known, but the combined effect of these alloy additions has not been analyzed so far. It was decided to check the total influence of nickel with a content between 1% to 3% and molybdenum with content from 0.1% up to 0.5%.

Keywords: welding, steel, ferrite, impact toughness

1. Introduction

The industry is constantly using new technologies with new materials [1-5]. Constructors are constantly looking for welding materials and processes that allow get high impact toughness at low temperatures [6-7]. The choice of chemical composition of steel and welding consumables plays a large role in this. Especially nickel, molybdenum, nitrogen are regarded as the important elements effecting on mechanical properties and metallographic structure of low alloy welds. However there is different influence of those elements on mechanical properties of welds [8-9]. In general, the influence of molybdenum and nickel on impact toughness is well known and there are several publications. Separated influence of Ni and Mo on WMD properties was usually analyzed. The combined effect of nickel and nitrogen as well as molybdenum and nitrogen on weld properties were examined [5]. The combined effect of nickel and molybdenum influence on WMD properties has not been analyzed carefully yet. There were even given some mathematical equations regarding impact toughness (at temperature +20ºC and –40ºC) of welds in terms of the amount of nitrogen and molybdenum (separate influence only) in [5].

For temperature +20ºC:

$$U_{+20}^{\mathrm{Mo}} = 265 - 66 \cdot \mathrm{Mo} - 0,8 \cdot N \quad (1)$$

and for temperature –40ºC:

$$U_{-40}^{\mathrm{Mo}} = 135 - 46 \cdot \mathrm{Mo} - 0,45 \cdot N \quad (2)$$

where:

U_{+20}^{Mo} – impact toughness of weld metal deposit at +20ºC, J,
U_{-40}^{Mo} – impact toughness of weld metal deposit at –40ºC, J,
Mo – molybdenum contents (in range 0.27 to 0.52%) of weld metals deposit, %,
N – nitrogen contents (in range 78 ppm to 168 ppm) of weld metals deposit, ppm.

There were also even given mathematical equations regarding impact toughness (at temperature +20ºC and –40ºC) of welds in terms of the amount of nitrogen and nickel in WMD [5].

for +20ºC:

$$U_{+20}^{\mathrm{Ni}} = 267.79 - 32.23 \cdot \mathrm{Ni} - 0.58 \cdot N \quad (3)$$

and for temperature –40ºC:

$$U_{-40}^{\mathrm{Ni}} = 115.55 + 21.23 \cdot \mathrm{Ni} - 0.54 \cdot N \quad (4)$$

where:

U_{+20}^{Ni} – impact toughness of weld metal deposit at +20ºC, J,
U_{-40}^{N} – impact toughness of weld metal deposit at –40ºC, J,
Ni – nickel contents (in range 1.1 to 1.8%) of deposits, %,
N – nitrogen contents (in range 50 to 250 ppm) of weld metal deposits, ppm.

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Furthermore, on the basis of the results of the influence of the variable amounts of Mo with *N* and Ni with *N* it was not possible to obtain more than 50% of acicular ferrite in WMD that guaranties good impact toughness of WMD. Good mechanical properties of weld correspond also with low-oxygen processes [10-11]. Separate amount of nickel and molybdenum in low-oxygen processes (amount of oxygen is on the level of 400 ppm) have strong influence on metallographic structure because of the influence on acicular ferrite (AF) formation [12-14]. Absorbed energy in terms of the amount of molybdenum in metal weld deposit is shown in fig. 1 and absorbed energy in terms of the amount of molybdenum in metal weld deposit is shown in Fig. 2.

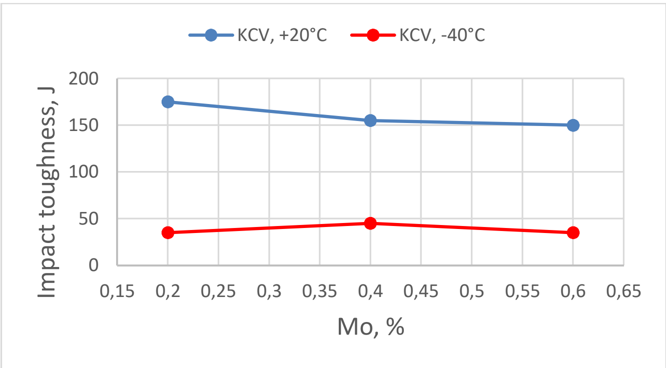

Fig. 1. Relations between the variable amount of Mo and the impact toughness of WMD [11]

Analysing Fig. 1 it is possible to deduce that impact toughness of metal weld deposit is also quite positively affected by the amount of molybdenum. Amount of 0.4% Mo (having 0.07% C) could be treated as optimal. Absorbed energy in terms of the amount of nickel in metal weld deposit is shown in Fig. 2.

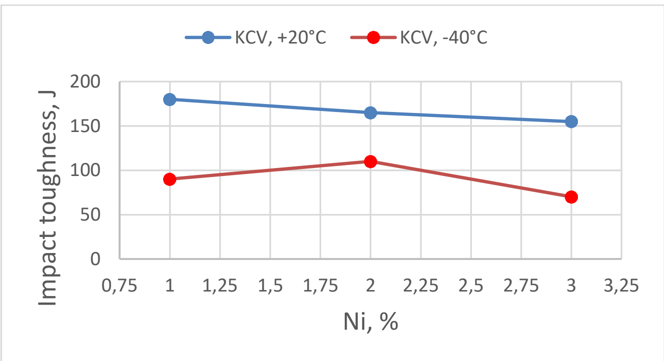

Fig. 2. Relations between the variable amount of Ni and the impact toughness of WMD [11]

Analysing Fig. 2 it is possible to deduce that impact toughness of metal weld deposit (having 0.07% C) is even more positively affected by the amount of nickel. Amount of 2% Ni could be treated as optimal. The combined effect of molybdenum and nickel on WMD properties has not been thoroughly tested yet.

2. Aim and plan of research

It was decided to investigate the properties of WMD, depending on the various parameters of the MMA process. To assess the effect of nickel and molybdenum on mechanical properties of deposited metals there were used basic electrodes prepared in experimental way. The electrode contained constant or variable proportions of the following components in powder form:

technical grade chalk	30%,
fluorite	20%,
rutile	4%,
quartzite	3%,
ferrosilicon (45% Si)	6%,
ferromanganese (80%Mn)	4%,
ferrotitanium (20%Ti)	2%,
iron powder	31%.

This principal composition was modified by separate additions (at the expense of iron powder):

nickel powder	up to 6%,
molybdenum powder	up to 2%.

The principal diameter of the electrodes was 4 mm. The standard current was 180 A, and the voltage was 22 V. A typical weld metal deposited had following chemical composition:

0.08% C	0.012% Al,
0.82% Mn,	0.017% S,
0.41% Si,	0.014% P,
nitrogen	(from 53 to 62 ppm),
oxygen	(from 370 to 415 ppm).

In order to prepare weld metals containing different concentration of nickel and molybdenum, respectively nickel powder and molybdenum powder were added to the coatings of electrodes. A variation in the nickel amount in the deposited metal was analysed from 1 up to 3% in weld. A variation in the molybdenum amount in the deposited metal was analysed from 0.2 up to 0.6% in weld. The nitrogen content was in controlled narrow range from 53 ppm up to 62 ppm. The oxygen content was in narrow range from 340 to 415 ppm.

3. Metal Weld Deposit Testing

After the welding process using basic coated electrodes there were gettable metal weld deposits with the variable amounts of nitrogen and molybdenum in it (which had the following contents rounded up: 1% Ni, 2% Ni, 3% Ni, 0.2% Mo, 0.4% Mo and 0.6% Mo). After the chemical analysis, micrograph tests, and Charpy notch impact toughness tests of the deposited metal were carried out. The Charpy tests were done mainly at –20°C, –40°C and –60°C with 3 specimens having been tested from each weld metal. On the bases of the chemical analysis, micrograph and impact Charpy tests results there was analysed the influence of nickel and molybdenum contents on the impact toughness properties of weld metal deposit according to the standard ISO 148-1 [15]. Samples for impact testing were prepared according to the standard ASTM A370 [16]. Fatigue test was another part of investigation according to the standard EN 76/H 04326. The acicular ferrite (AF) and MAC phases (self-tempered martensite, retained austenite, carbides) in the WMD was analyzed using a Hitachi S.4200 (Gray) scanning microscope (magn. 1000×) equipped with a video card and a camera. This allowed for the observed structure to be saved as a bmp file for loading data to the MeTilo program. The photographic documentation was done at an 800 × 600 screen resolution. Using MeTilo measuring tools, the image was analyzed using mathematical morphology methods. The measurement error in calculating amount of acicular ferrite in WMD did not exceed 1%. Amount of MAC phases was only estimated because of very low amount of carbon in the WMD. The percentage of acicular ferrite in the WMD was estimated as a result of that test, and was also tested by X-ray analysis as an additional observation.

4. Results and discussion

On the bases of the Charpy test results shown on the table 1 there was analysed the (common and separate) influence of molybdenum and nickel on the impact toughness properties at –20° C.

TABLE 1

Relations between impact toughness properties of metal weld deposits at –20°C and the combined amount of Ni and Mo

Nickel contents [%]	Molybdenum contents [%]	Impact toughness of weld metal deposits at (–20°C) [J]
1.13	—	121
1.26	0.21	137
—	0.23	72
1.81	—	131
1.73	0.42	99
—	0.44	93
2.74	—	97
2.73	0.45	72
2.71	0.57	62
—	0.57	51

Very good plastic properties of the joint were easily obtained for all tested deposits with maintaining the 2 impact class (absorbed energy higher than 47 J at temperature –20°C). On the bases of the Charpy test results shown on the table 2 there was analysed the influence of molybdenum and nickel on the impact toughness properties at –40°C.

Analyzing the array data it can be seen that nickel is more beneficial to weld impact toughness than molybdenum. The best plastic properties have a weld metal totally containing approx. 1% Ni and 0.2% Mo. These results were confirmed at both negative temperatures. All tested weld metal deposits had second impact toughness classes, while weld metal containing a higher total nickel and molybdenum content did not guarantee good impact strength. WMD containing about 1% Ni or a totally 1%

TABLE 2

Relations between impact toughness properties of metal weld deposits at –40°C and the combined amount of Ni and Mo

Nickel contents [%]	Molybdenum contents [%]	Impact toughness of weld metal deposits at (–40°C) [J]
1.13	—	99
1.26	0.21	115
—	0.23	51
1.81	—	109
1.73	0.42	78
—	0.44	69
2.74	—	81
2.73	0.45	62
2.71	0.57	below 47
—	0.57	below 47

Ni and 0.2% Mo have very high impact strength at –40°C (forth impact toughness classes, i.e. absorbed energy higher than 47 J at temperature –40°C). For deposits (1%Ni and 1% Ni, 0.2%Mo) with the best impact strength (above 100 J) at –40, it was decided to test the impact strength at –60°C (table 3).

TABLE 3

Relations between impact toughness properties of metal weld deposits at –60°C and the combined amount of Ni and Mo

Nickel contents [%]	Molybdenum contents [%]	Impact toughness of weld metal deposits at (–40°C) [J]
1.26	0.21	63
1.81	—	77

Very good plastic properties of the joint were obtained with maintaining the 6 impact class (absorbed energy higher than 47 J at temperature –60°C). In order to understand so high impact toughness properties of welds, it was decided to check the acicular ferrite content and MAC phases (self-tempered martensite, retained austenite, carbide) amount in the tested joints table 4. WMD containing Mo and Ni has excellent plastic

TABLE 4

Acicular ferrite and MAC phases in WMD

Nickel contents [%]	Molybdenum contents [%]	Acicular ferrite in weld [%]	MAC phases in weld [%]
1.13	—	56	2
1.26	0.21	58	2
—	0.23	49	2
1.81	—	53	2
1.73	0.42	48	2
—	0.44	49	2
2.74	—	50	2
2.73	0.45	46	3
2.71	0.57	44	3
—	0.57	45	3

properties which are not explicitly confirmed in literature. It can be assumed that molybdenum (ferrite stabilizer) in WMD can lead to a significant ferrite grain disruption, which in connection with the optimal chemical composition will give an optimal effect. It can be also assumed that nickel (austenite stabilizer) in WMD can lead to the reduction of unfavorable MAC phases (self-tempered martensite, retained austenite, carbide). MAC phases reduce impact toughness of weld and should not be higher than 4% in WMD.

It was easy to state that weld metal deposit having a high impact toughness (tables 1-3) had a sufficiently high acicular ferrite content and low MAC phases content. Amount of acicular ferrite in WMD after welding was on the variable level depending on the chemical composition of the welds (Ni, Mo). Acicular ferrite with percentage above 55% was gettable only for deposits having respectively 1% Ni or total of 1% Ni and 0.2% Mo. Acicular ferrite of deposits having 1% Ni is shown on figure 1 and acicular ferrite of total of 1% Ni and 0.2% Mo is shown on figures 3,4.

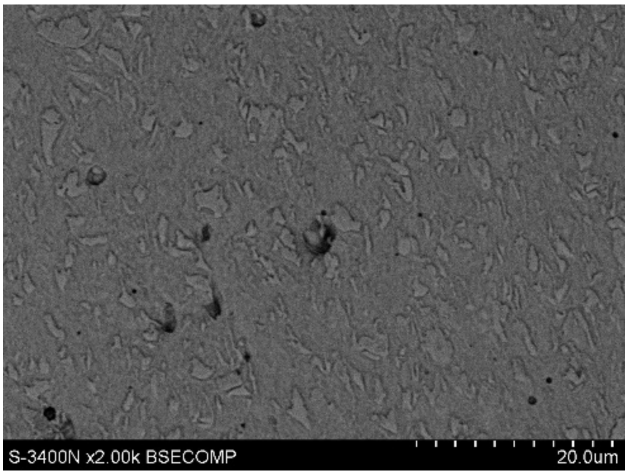

Fig. 3. Acicular ferrite in WMD totally having 1% Ni and 0.2% Mo

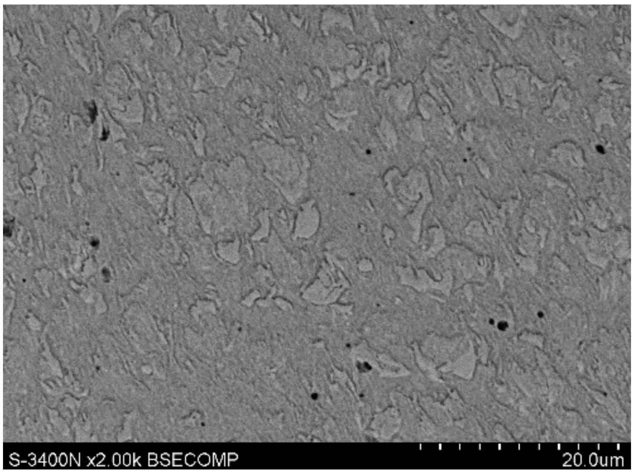

Fig. 4. Acicular ferrite in WMD having 1% Ni

In the last part of the research it was decided to examine the fatigue strength of two weld metal deposits which guarantees the highest level of ferrite and having the best impact strength (deposits with 1% Ni and total 1% Ni and 0.2% Mo). In responsible weld structures there are two general types of tests conducted: impact toughness and fatigue tests. The second kind of mentioned tests focuses on the nominal stress required to cause a fatigue failure in some number of cycles. This test results in data presented as a plot of stress (S) against the number of cycles to failure (N), which is known as a S-N curve, shown in figures 5,6.

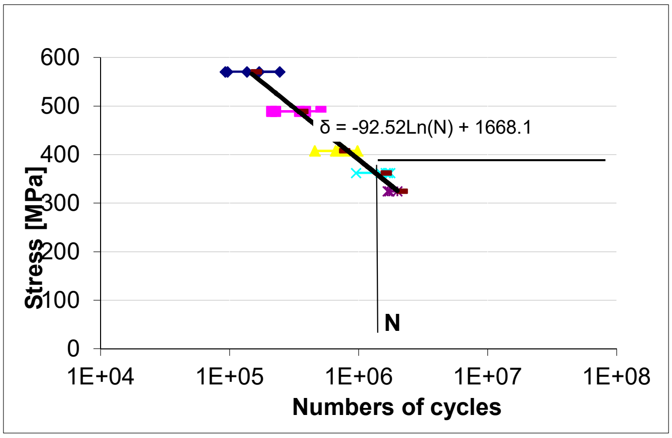

Fig. 5. S-N Fatigue properties for WMD with 0.2% Mo and 1% Ni

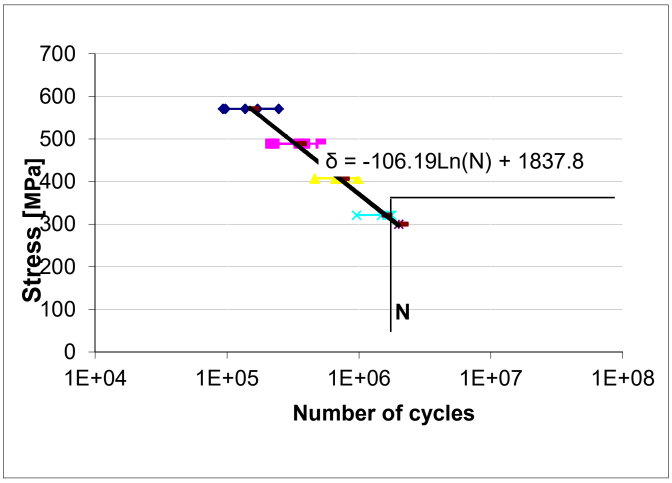

Fig. 6. S-N Fatigue properties for WMD with 1% Ni

Looking for the S-N curve it easy to deduce, that amount of 0.2% Mo and 1% Ni could be treated as optimal.

5. Conclusions

Weld metal deposit with various combined contents of nickel and molybdenum were examined. The plastic properties of the joint are much better effected by nickel than molybdenum. For the first time it was decided to find out what is the combined effect of nickel and molybdenum. For this purpose basic electrodes was prepared in experimental way, that allowed to obtain a weld metal deposit with a varied combined content of nickel and molybdenum. It turned out that the best impact strength in low temperature has a deposit with a combine content of 1% and 0.2% Mo. This corresponds to the high amount of acicular ferrite and low MAC content in weld metal deposit. Deposits having 1% Ni or 1% Ni with 0.2% Mo guarantee high fatigue strength. Concluding this paper it is easy to deduce that:

1. Nickel and molybdenum could be treated as elements positively influencing mechanical properties of WMD,
2. Weld metal deposit having 1% Ni and 0.2% Mo could guarantee high impact toughness and good fatigue properties,
3. In weld metal deposit having 1% Ni and 0.2% acicular ferrite is on the level of 58%.

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