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# INCLUSIONS IN STEEL COATED ELECTRODES WELDS OF CAR BODY

**Summary.** The goal of this project (BK-284/RT1/2007) is to chose the proper method of car body welding. SMAW could be treated as the main method used in the transport industry. Properties of metal weld deposits depend on many conditions. This paper attempts to study first of all the role of oxide inclusion sites on the transformation austenite→acicular ferrite in steel weld metal deposits and their toughness. Properties of metal weld deposits depend on the amount of acicular ferrite in them. For good toughness over a range of temperatures, metal weld deposits should have a high amount of acicular ferrite. Different basic and rutile electrodes were used in order to obtain different as-deposited weld compositions. Impact toughness tests of various deposits were carried out. The microstructure of the welds with different oxygen levels, the inclusion size distribution and approximate chemical composition of inclusions are characterized. Most observations and measurements were done with a scanning electron microscope equipped with an energy-dispersive X-ray spectrometer. The result of the present study implies that it is advantageous to keep oxygen contents in basic and rutile deposits as low as possible when well-developed microstructures of acicular ferrite are desired.

# WTRĄCENIA W SPAWANYCH ZŁĄCZACH NADWOZI SAMOCHODOWYCH, WYKONANYCH ELEKTRODAMI OTULONYMI

**Streszczenie.** Celem pracy (BK-284/RT1/2007) jest wybór właściwej metody spawania nadwozi samochodowych. Spawanie SMAW może być traktowane jako główna metoda spawania sprzętu transportowego. Właściwości stopiwa elektrodowego zależą od wielu czynników. W artykule przeanalizowano wpływ wtrąceń tlenkowych na przemianę austenit→ferryt AF oraz na udarność stopiwa. Właściwości stopiwa zależą od ilości zawartego w nim ferrytu AF. W celu zapewnienia wysokiej udarności stopiwa w szerokim zakresie temperatur, powinna znajdować się w nim duża ilość ferrytu AF. Do wykonania różnych rodzajów stopiw zastosowano różne odmiany elektrod zasadowych oraz rutylowych. Przebadano udarność stopiw wykonanych różnymi metodami. Przeanalizowano mikrostrukturę stopiw o różnych zawartościach tlenu, określono procentowy rozkład wielkości wtrąceń znajdujących się w stopiwach, określono również skład chemiczny ujawnionych wtrąceń. Większość obserwacji oraz badań przeprowadzono z użyciem elektronowego mikroskopu skaningowego, wyposażonego w przystawkę do mikroanalizy rentgenowskiej. Uzyskane wyniki wskazują na to, iż korzystnie jest utrzymywać zawartość tlenu w stopiwie elektrod zasadowych jak i rutylowych na możliwie niskim poziomie, kiedy wymagana jest dobrze rozwinięta struktura ferrytu AF.

# 1. INTRODUCTION

Crash behaviour and light weight have become the major design criteria for car bodies. Car body should have the best mechanical properties: good impact toughness and high strength resistance, it is why steel and welding technology is still used for car body structure. Properties of steel welds are strongly dependant on structure. Acicular ferrite is treated as the most beneficial phase in steel MWD [1-7]. Acicular ferrite is mainly formed in the interior of the original austenitic grains by direct nucleation from the inclusions. The mechanism by which acicular ferrite grows is still not well understood [1-5]. Acicular ferrite has been known to provide an optimal combination of high strength and good toughness due to its refined and interwoven structure [2-4]. The role of oxide inclusion sites on the transformation austenite→acicular ferrite in steel weld metal deposits has been well analyzed in the last 20 years [1-15]. Authors of the main publications are not of the same opinion about nucleation of acicular ferrite [5]. Authors of the main publications propose that the optimal content of oxygen should not be greater than 600 ppm, [9]. The amount of oxygen in welds, i.e. oxide inclusions and metallographic structure can be regarded as the important factors on impact properties and metallographic structure. This project attempts to study the role of oxide inclusion sites on the transformation austenite→acicular ferrite in steel rutile and basic deposits and their toughness.

# 2. EXPERIMENTAL PROCEDURE

## Electrodes and Welding Procedure

To asses the effect of oxygen on mechanical properties of deposited metals basic and rutile electrodes prepared in an experimental way were used. The electrodes contained in coatings constant or variable proportions of the following components in powder form:

| | | | |
|---|---|---|---|
| technical grade chalk | 35 % | ferrosilicon (45%Si) | 6 % |
| fluorite | 20 % | ferromanganese (80%Mn) | 4 % |
| | | iron powder | 35 % |

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

| | |
|---|---|
| rutile (titanium oxide) | from 3 to 19 % |
| synthetic galaxite powder | from 3 to 6 % |
| aluminium powder | up to 2% |
| titanium powder | up to 2% |
| ilmenite (iron titanium oxide) | up to 4% |

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

| | |
|---|---|
| approx. 0.08 % C | from 0.01 to 0.045 % Al |
| from 0.4 to 0.8 % Mn | up to 0.08 % Ti |
| approx. 0.33 % Si | up to 90 ppm N |
| approx. 0.02 % P | oxygen - from 293 to 794 ppm |
| approx. 0.02 % S | |

Galaxite and rutile were added to the coatings of electrodes in order to prepare weld metals containing higher concentration of $(Mn,Fe)(Al,Fe)_2O_4$ and TiO inclusions and therefore also higher oxygen content in metal weld deposit. A variation in the oxygen amount in the deposited metals was also varied by adding aluminium and titanium powders to the electrode coatings. As a result after welding the amount of oxygen in the weld metal was on a level between 293 and 794 ppm. With increasing galaxite and rutile contents electrode coatings from 3 to 10 % the oxygen contents in weld deposits rose from approx. 300 ppm to 800. Simultaneous the Al and Ti amounts in weld deposits are being lowered from 0.08% to 0.03%.

**Weld Metal Testing**

Chemical analysis, micrograph tests, and Charpy V-notch impact toughness tests of the deposited metal were carried out. The 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. Charpy tests results are given in Table 1 and 2. The inclusion size distribution and chemical composition of inclusions are given in the Figures 3 to 6. Most observations and measurements were done with a scanning electron microscope Philips XL-30 equipped with an energy-dispersive X-ray spectrometer. The inclusion size, shape and chemical composition were determined on specimens for impact tests.

## 3. RESULTS AND DISCUSSION

On the basis of the results (shown in tables 1, 2) the oxygen influence and metallographic structure on the impact toughness of metal weld deposit were analyzed:

Tab. 1.

Impact toughness of MWD and the the amount of oxygen in basic MWD

| Oxygen in weld metal deposits, PPM | Acicular ferrite, % | Impact toughness of weld metal deposits at 20°C, J | Impact toughness of weld metal deposits at -40°C, J | Galaxite or rutile in coatings, percentage |
|---|---|---|---|---|
| 293 | 65 | 176 | 37 | 4% of galaxite |
| 345 | 72 | 207 | 48 | 4% of rutile |
| 396 | 64 | 189 | 33 | 8% of rutile |
| 443 | 58 | 177 | 28 | 8% of galaxite |
| 497 | 57 | 169 | 23 | 10% of galaxite |

Tab. 2.

Impact toughness of MWD and the the amount of oxygen in rutile MWD

| Oxygen in weld metal deposits, PPM | Acicular ferrite, % | Impact toughness of weld metal deposits at 20°C, J | Impact toughness of weld metal deposits at -40°C, J | Galaxite or rutile in coatings, percentage |
|---|---|---|---|---|
| 632 | 49 | 143 | 19 | 13% of rutile |
| 794 | 37 | 137 | 16 | 19% of rutile |

Tables 1 and 2 shows that at these amounts of oxygen in metal weld deposit oxygen has influence on impact toughness properties of metal weld deposits (measured at 20°C and -40°C). Amount of oxygen, presented in the table 1, has not a very great influence on the percentage of acicular ferrite in basic deposits that is always on similar level. Amount of acicular is strongly lower in rutile deposits (table 2). Table 1 shows that 354 ppm of oxygen in metal weld deposits yields the best impact strength results of metal weld deposits. To determine the reasons for the different values of impact strength results for weld metal deposits metallographic and fractographic tests were carried out. Estimation of grain size by microscopic method are shown in figure 1 and 2.

The mechanism by which acicular ferrite grows is not well understood, but it is known that good toughness of MWD strongly depends on the percentage of acicular ferrite in deposit. However some authors are of a different opinion about that. Estimation of grain size by microscopic method proved that in rutile deposits it is always below 50% of AF meanwhile in basic deposits there was much higher amount of AF on the level of 60%. To analyse the reasons for the different values of impact strength results for weld metal deposits fractographic analysis were also carried out. Inclusion size distributions for metal weld deposits with two different levels of oxygen were analyzed using a Philips XL-30 scanning electron microscope. Inclusion size distributions for basic and rutile metal weld deposits were carried out (figure 3, 4).

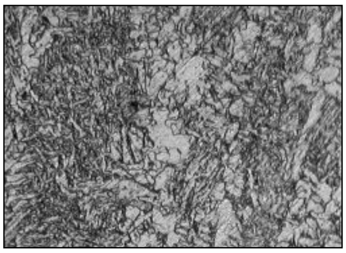

Fig. 1. Estimation of grain size in rutile MWD, 30% of acicular ferrite, 100X
Rys. 1. Oszacowanie wielkości ziarna w rutylowym stopiwie elektrodowym, zawartość ferrytu AF 30%, 100X

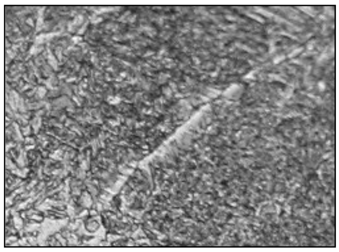

Fig. 2. Estimation of grain size in basic MWD, 55% of acicular ferrite, 100X
Rys. 2. Oszacowanie wielkości ziarna w rutylowym stopiwie elektrodowym, zawartość ferrytu AF 30%, 100X

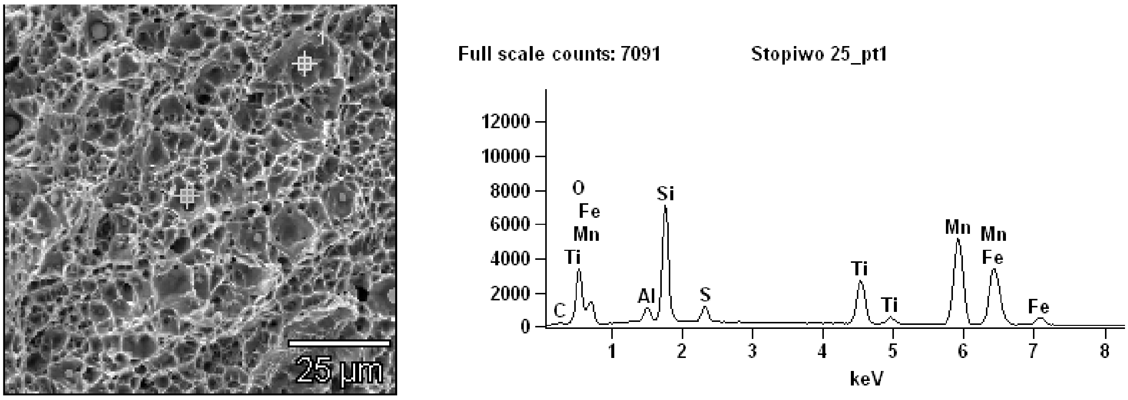


Fig. 3. Micrograph of inclusions in basic metal weld deposits with the most beneficial level of oxygen (345 PPM)
Rys. 3. Skład chemiczny wtrąceń w stopiwie elektrod zasadowych o najkorzystniejszej zawartości tlenu (345 PPM)

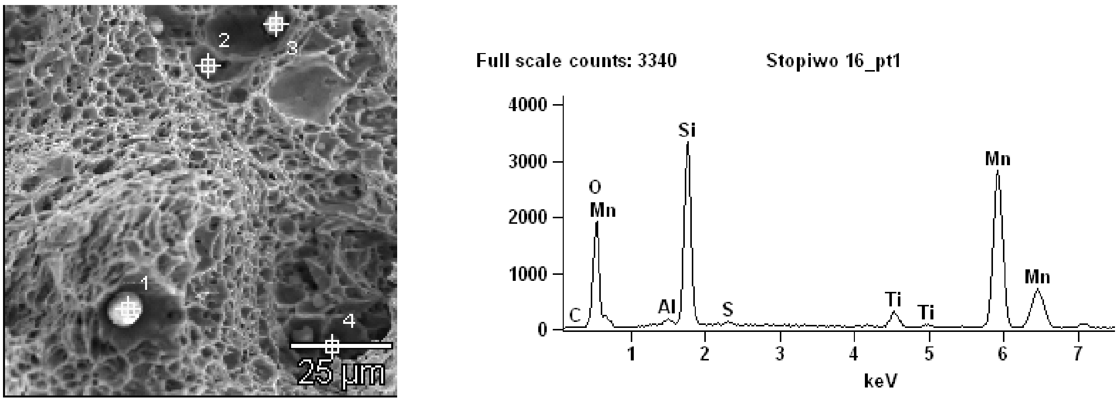


Fig. 4. Micrograph of inclusions in rutile metal weld deposits with higher level of oxygen (794 PPM)
Rys. 4. Skład chemiczny wtrąceń w stopiwie elektrod rutylowych o wyższej zawartości tlenu (794 PPM)

The size of inclusions is dependant on the oxygen amount in the metal weld deposits. The inclusions have mainly diameters from 0.3 µm to 0.6 µm for lower amounts of oxygen in basic metal weld deposits, and diameters from 2 µm to 9 µm for higher amounts of oxygen in rutile metal weld deposits (figure 5, 6). Additional inclusions observations and measurements were done using a scanning electron microscope equipped with an energy-dispersive X-ray spectrometer to get approximate size and chemical composition of inclusions. Approximate chemical composition of inclusions (chemical elements in them) is shown in figures 3 and 4.

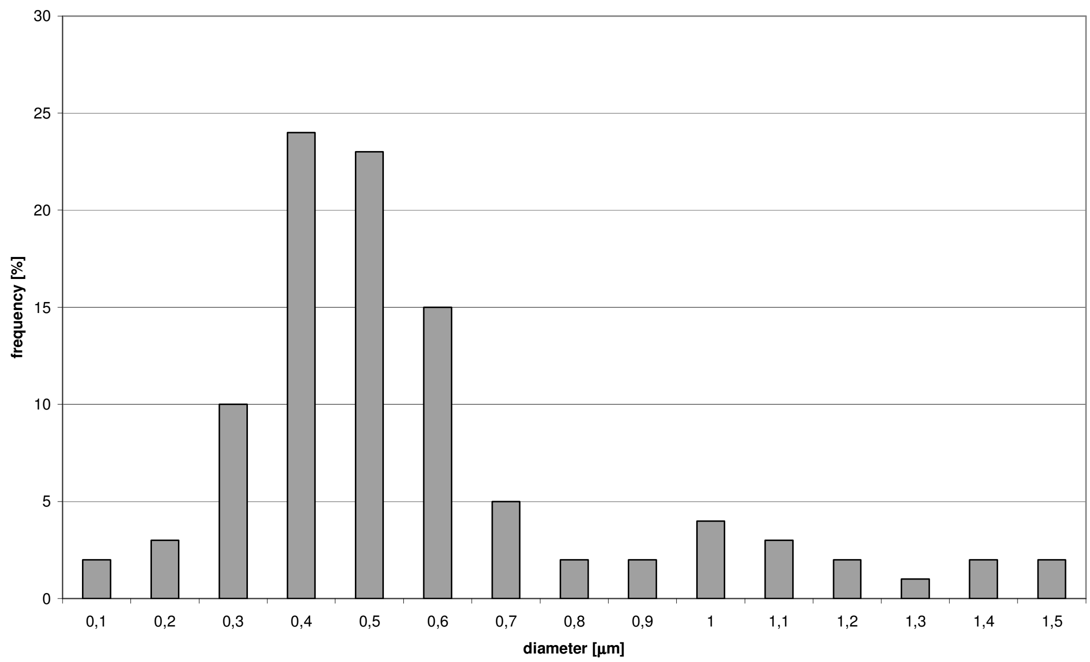


Fig. 5. Inclusion size distributions for metal weld deposits with 345 ppm of oxygen
Rys. 5. Rozkład wielkości wtrąceń w stopiwie o zawartości tlenu 345 PPM

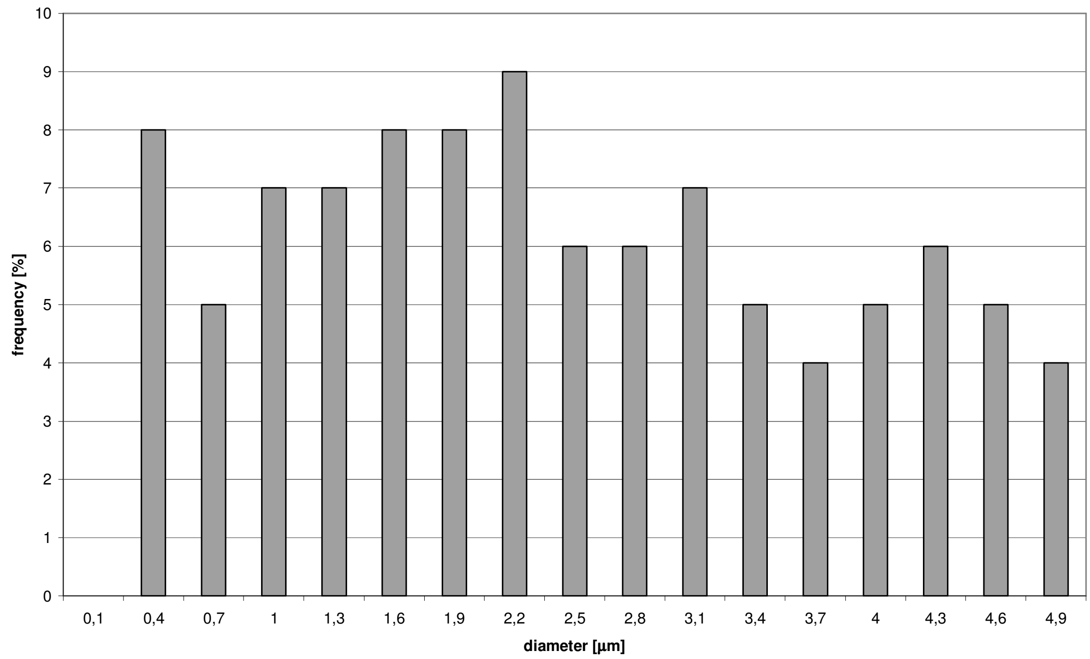


Fig. 6. Inclusion size distributions for metal weld deposits with 632 ppm of oxygen
Rys. 6. Rozkład wielkości wtrąceń w stopiwie o zawartości tlenu 632 ppm

After microscope observations it was determined that the amount of oxygen may have some influence on the size of inclusions and for their chemical character. For two different levels of oxygen in basic and rutile metal weld deposits, the size of inclusions was studied in similar elements such as: O, Fe, Al, Mn, Ti, Si. Analyzing Figure 3 and 4 it is possible to deduce that inclusions are heterogeneous nature and that they could play a great role in forming acicular ferrite. They have mainly a FCC lattice structure, and an adequate matching tendency to Fe lattice and it could possibly be compatible with the BCC lattice structure of ferrite that is beneficial for the transformation austenite→acicular ferrite. This could explain why after the transformation of austenite there results a variable amount of acicular ferrite. Also the size of inclusions could have an influence on forming acicular ferrite and thereby resulting in obtaining better impact toughness properties. Size of inclusions in rutile deposit is much bigger than in basic deposit. The most beneficial inclusion diameter for AF forming should be on the level of 0.4 μm that corresponds with a small level of oxygen in basic MWD. Nevertheless there were also gettable small inclusions in rutile deposits, which have even two times higher amount of oxygen.

## 3. CONCLUSIONS

Examination of the influence of variable amounts of oxygen and the metallographic structure on impact properties of metal weld deposits using basic electrodes resulted in the following conclusions:
1. Crash behaviour and light weight have become the major design criteria for car bodies. Steel car body welded construction should have the best mechanical properties: good impact toughness and high strength resistance.
2. The toughness of the metal weld deposits is affected by the amount of oxygen and the amount of acicular ferrite in the weld metal.
3. Inclusions with diameters from 0.2 μm to 0.6 μm could be treated as the strongest acicular ferrite formers. Those inclusions were gettable in basic and rutile MWD.
4. Rutile electrodes could be treated as a proper electrodes for welding car bodies.

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