INVESTIGATIONS ON MAG WELD METAL FOR CRITICAL VALUATION OF FRACTURE MECHANICS PROPERTIES

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ABSTRACT

An investigation was carried out to determine the structure and the impact properties of multipass MAG weld metals using precracked Charpy type specimens. Force and deflection over time and force over deflection were registered. The plastic deformation preceding the fracture apparently took place in very different way. According to the position of the notch with respect to the weld beads deposited, both different Charpy-V and J_c values (using precracked specimens) were obtained. The weld metal material properties are of great importance for the brittle fracture safety. Tolerable defects in the welds can be evaluated by fracture mechanics characteristics.

INTRODUCTION

A joint research program of the Institute for Materials Science and Material Testing of TU Vienna (Austria) and the Institute for Technology and Materials Science of TU Budapest (Hungary) aimes at the structure and the material properties of metal active gas (MAG) multi pass weld metals.

This high efficiency welding process is widely used in steel constructions in both, the semiautomatized and the fully automatized version. The application of the most economical solid wire MAG welding is generally limited to ambient temperatures above- 20°C, since the resilience of the weld metal is not sufficiently high and the Charpy V values at and below -20°C do not meet the requirements. Furthermore no quantitative defect evaluation is possible by using Charpy V notch test data.

The goal of the investigation is to achieve better notch toughness in the weld metal by optimum welding technology and further to evaluate material characteristics, which can be used directly in determining the brittle fracture safety of the weld metal and the significance levels of weld defects.

This paper presents the results of the first part of these investigations.

PREPARATION OF WELD METALS

The edge bevelling was chosen according to ISO, as illustrated in Fig. 1. The base material was a 500 MPa type fine grain structural steel, with the following chemical composition: 0,2 % C, 0,42 % Si., 1,36 % Mn, 0,42 % S, 0,030 % P. The welding wire was a solid MnSi wire type VIH-2, Ø 1,2 mm, made by SKÜ-Hungary. The weld metal was made with a mechanised CO_2 GMAW welding machine, type ADG-502, multipass, without preheating, the interpass temperature was max. 250°C (measured). The welding parameters were the followings:

Shielding gas: CO_2 with H_2O checking

Gas flow rate: 14 - 16 l/min
Wire stick out: 12 - 16 mm
Nozzle distance: 15 -25 mm/ 22-25 mm for welding passes No.1. and 2./
Welding speed: 300 mm/min
Voltage: 26-26 Volts.
Current: 220-240 Amps.

INVESTIGATIONS AND RESULTS

Preliminary tests had shown that the surface of fracture of ISO-V notched bar impact test specimens taken from the weld metal had a locally different appearance in the transitional region: areas with typical low-ductility fracture and otherswith a ductile fracture. The idea suggested itself that this distinct fracture behaviour of various areas was due to the influence of a subsequent welding pass which principally can act by two mechanisms, namely remelting and refining or heating a part of the foregoing pass.

From this observation it was concluded that the position of the notch relative to the multipass seam should affect the result of impact testing of the weld metal. In order to give evidence of this conclusion ISO-V impact test specimens were taken from the two positions shown in Fig.1. It is obvious that for specimens from position A a larger ratio of the cross section at the notch is being influenced by a subsequent welding pass than for specimens from posisiton B for which the notch is off the middle of the weld seam. Testing such specimens at -20°C indeed proved a clear influence of the position of the specimens on the impact toughness:
The absorbed energy was essentially higher for the middle--specimens A than for the off-middle specimens B, namely 64 J against 44 J, each being a mean value from six specimens.

These results justified a more detailed study. The first series of investigations aimed at the influence of the testing temperature on the result of ISO-charpy-V tests for both, middle and off-middle specimens according to position A and B respectively (Fig.1.). It can be seen from Fig.2. that in the whole range of testing temperatures the specimens from the middle position A had a superior notch toughness and that the difference between the samples of the two posotions A and B

reached a maximum at -20°C. Fig.2 also illustrates that the scatter band of the results was wider for the off-middle position B specimens.

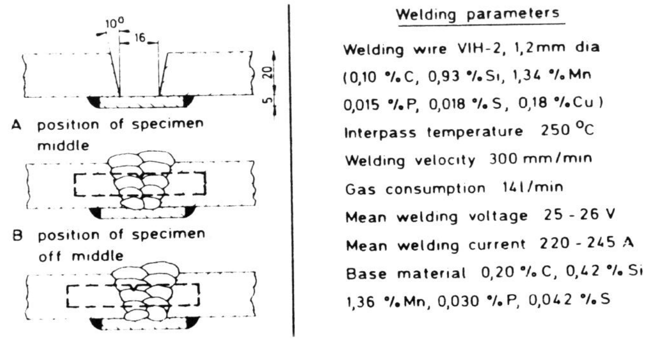

Fig.1. MAG-welding:Preparation, position of specimens and welding parameters

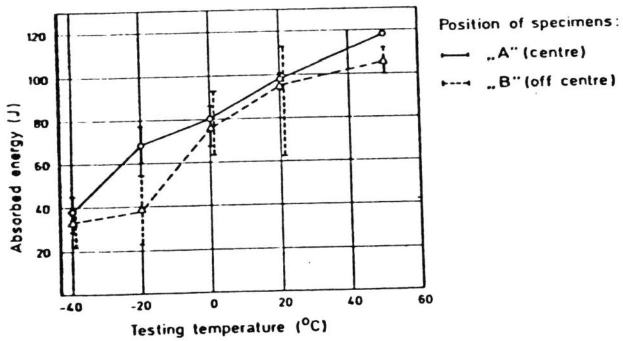

Fig.2. Results of ISO-Charpy-V-test

A further confirmation for the difference of ductility for specimens taken from the two different positions was obtained in Fig.3.
Precracking of the specimens was accomplished by using an electromagnetic resonant machine at about 200 cycles/second. The amplitudes were held far below the limits given in ASTH E 399 or E 813; a lower scatter and a straighter crack front was achieved by this means.

A special device, developed by the TVFA of the Technical University Vienna applies isolated foils to follow the fatique crack propagation. The change in resistance is used to control the decrease of force amplitude which takes place in very small steps. An automatic registering unit gives full documentation on every precracking procedure.

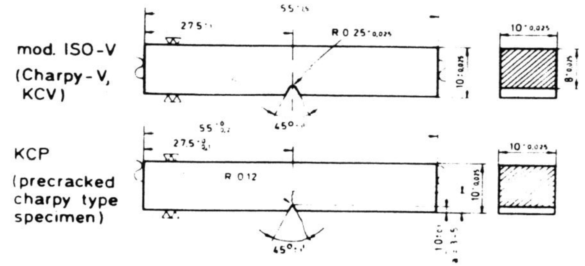

Fig.3. ISO-V and precracked charpy type impact specimens

The impact pendulum, type Schnadt, is equipped not only for the impact velocity of 5 m/s but also for 0,1 m/s: a chisel actuated by an excenter is mounted on one side of the machine and the impact velocity is reduced by 50:1 to 0,1 m/s. The absorbed energy can be read in either case on the free side of the pendulum.

Due to the very rigid design of the Schnadt-type impact tester and as the centre of gravity of the moving masses is checked and corrected very carefully, the vibration is minimized. Therefore the instrumentation of the hammer already made several years ago [ASK AN 425, Rev.1], allowed to trace force-time and force-bending deflections.

Fig.4. shows the specific absorbed energy per cross sectional area for precracked charpy-type specimens taken from the middle (A) and off middle (B) position in the MAG weld metal as a function of testing temperature. It can be seen that for the entire range of temperatures above - 40°C the ductility of specimens A clearly exceeded that of the off-middle specimens B. It has to be noted that for all these precracked specimens the absorbed energy had to be related to the net fracture section of each specimen as this net section differed from the standard value and varied slightly from specimen to specimen because of precracking. With the chosen impact velocity of 0,1 m/s an attempt was made to adapt to the strain rate observed for many actual structures.

The fracture appearance of the precracked specimens are in full agreement with the results of impact testing. For the specimens of both positions A and B, the cleavage fracture area increases with decreasing temperature. However, the temperature for the same ratio of cleavage to ductile fracture is about 20°C lower for specimens from the middle position A than for

specimens from position B. Besides, the cleavage fracture areas of the latter specimens were coarser than those of specimens A tested at the same temperature.

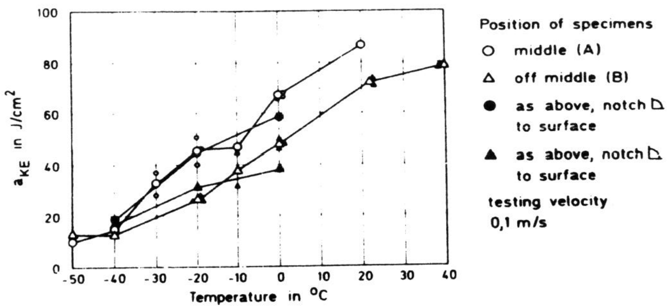

Fig.4. Specific absorbed energy per cross sectional area versus testing temperature for precracked charpy type specimens taken from MAG weld metal

With the use of precracked charpy-type specimens produced and prepared under strict observation of ASTM E 399 ASK AN 425, Rev.1. (except a relaxation on precrack front geometry) and with taking account of inertia effects at the very short period of time elapsing to fracture, linear elastic fracture mechanics characteristics, i.e. K_{IC}, under non-quasistatic loading could be measured.

For partly or fully ductile behaviour deflection measurements became necessary. The initation of crack propagation was taken as the point to define critical Crack Opening Displacement, COD, or J-Integral values δ_i or J_{IC}, also under non-quasistatic loading.

For many ductile metals crack initiation usually takes place at or near the maximum load point. In this work $J_{c\ max.}$, i.e. the path independent integral at the maximum load, has been used.

Typical load deflection diagrams are shown in Figs.5a,b,c,and d. A rather brittle behaviour with a sharp drop of load is represented by Fig.5a while the diagrams in Fig.5b and c are typical for specimens in which the crack successively propagated through coarse grained brittle and fine grained ductile areas. The curve results from the stepwise alternating high and low specific work needed for crack propagation. Lower and upper shelf behaviour is repeatedly passed in this case at the same temperature.

In Fig.5d both structures are in the upper shelf temperature region; a fully ductile fracture is observed.

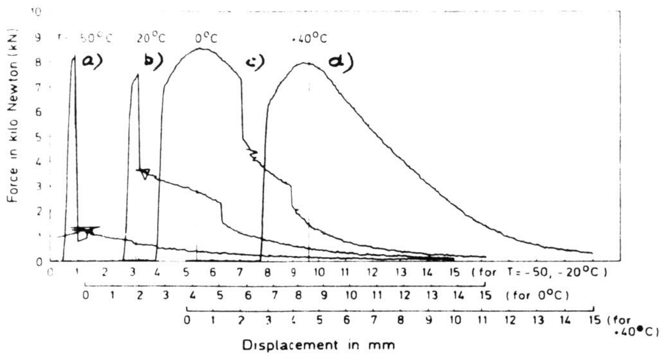

Fig.5. Force-bending displacement diagram of precracked charpy type specimens taken from MAG weld

The resulting J-values versus temperature for the realistic testing velocity are shown in Fig.6. It is evident that for the temperature range - 30°C to - 10°C specimens from the offmiddle position B were in the brittle and those from the middle position A were already in the ductile condition. The ductile-brittle transition temperature for specimens A is about 30°C lower than that for specimens B. This is in good agreement with the fracture appearance. It can be concluded

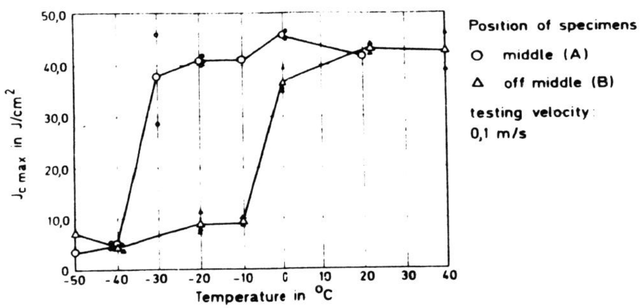

Fig.6. J-Integral versus testing temperature for precracked charpy type specimens taken from MAG weld metal

that under the given testing conditions simulating actual structural conditions only the weld metal in the middle position A is brittle fracture safe. From the fact that in this middle position a greater portion of the weld metal is being influenced by the action of subsequent welding passes than in the off-middle position it can be deduced more generally that the ductility of the weld metal is improved if a certain ratio of it undergoes a refinement by following welding passes resulting in a stepwise crack propagation. Specimens again taken from position A and B but having the notch perpendicular to the welding bead surface - and consequently also perpendicular to the notch direction of the specimens just described gave different results as far as the fracture appearence is concerned. No apparent distinct areas could be observed in general. However, for this more common notch position too, the J-integral values and also the corresponding impact test results (Fig.4.) are remarkably higher for specimens A than for the off middle specimens B in the temperature range -40 to 0°C.

Investigations aiming at the mechanism responsible for the notch toughness behaviour described are under way.
Acknowledgements are due to Messrs W.Kratzel, F.Loibnegger and W. Allertshammer for their help in preparing and conducting the laboratory tests.

SUMMARY

An investigation was carried out to determine the structure and impact properties of multipass MAG steel weld metals using precracked Charpy type specimens. Force and deflection over time and force over deflection were registered. Plastic deformation preceding fracture took apparently place in very different way depending wether the original cast columnar grain was subsequently altered and refined by following passes.

According to the position of the notch in respect of the weld beads deposited, both different Charpy-V and J_c values/using precracked specimens/ were obtained. The fractūre occured in several cases stepwise: this effect could be observed in the force-deflection diagram.

The weld metal material properties are of great influence on brittle fracture safety. Fracture mechanics characteristics allow the evaluation of tolerable defect levels in welds.

KEYWORDS

Steel, metal active gas welding, weld metal, impact properties, brittle fracture safety, significance of defects.