Influence of Dynamic Strain Ageing on Notch Toughness of Weld Deposits

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The purpose of this work is to study the susceptibility to dynamic strain ageing of weld deposits made with some covered electrodes and flux cored wires used in the welding of C-Mn steel plate. The influence of dilution and the effect of interstitial solute content is analyzed, trying to establish to what extent dynamic strain ageing contributes to fracture toughness degradation of multipass manual metal arc welds.

INTRODUCTION

There is recent evidence [1, 2, 3, 4] that in both, multipass M.M.A. and flux cored wire welds, overall toughness is controlled by root properties. This fact is indicative of phenomena that occur in this zone. It is presently acknowledged that some factors that can exert a marked influence on root run properties are:

a) Dynamic strain ageing, promoted by volume changes and thermal cycles during welding.

b) Dilution of weld metal by base plate material.

Dynamic strain ageing on Carbon steels has been thoroughly studied and the subject is widely covered in the literature [5, 6, 7, 8]. For strain ageing to occur, plastic deformation in a temperature range from about 100 to 300°C is required. Dynamic strain ageing is the result of interstitial solute atoms (Nitrogen and Carbon) segregation in the strain fields produced by dislocations in the α iron lattice. The interstitial atoms atmosphere so formed promotes locking of dislocations with the subsequent increment in strength and reduction in ductility.

As mentioned above, this can have some influence on mechanical properties of multipass welds, since the root run is in this case simultaneously subjected to the plastic deformation and thermal cycles, imposed by subsequent layers. For this reason, the study of room temperature mechanical properties of dynamic strain aged deposits may prove significant to understand welded joint behavior during service.

From the constitutional point of view, it is established that nitrogen is very effective promoting strain ageing. There is recent evidence that manganese contributes to reduce the effects of dynamic strain ageing. A possible reason for this is that although this element interacts weakly with C and N, it has been suggested that N atoms locate preferently next to Mn atoms, rather than on sites where they are surrounded by Fe atoms. This would lead to the formation of Mn-N pairs (and eventually Mn-C) thus reducing the mobility of the interstitial solutes.

As far as impact properties are concerned, Dynamic strain ageing reduces upper shelf fracture toughness, and raises ductile brittle transition temperature. Mn additions tend to reduce both these effects.

Most of our basic knowledge on dynamic strain ageing comes from experiments conducted on wrought materials, under controlled thermo-mechanical treatments. The situation is different with welded joints. In this case thermal cycles and deformations produced by the welding procedure are in general only roughly estimated.

Charpy tests conducted by Cochrane et al. [2] on M.M.A. welds made on 40 mm. thick plate, using different electrodes and similar base metal and procedure, showed that samples machined from the root region exhibited a toughness degradation which completely overrides the effects of the deposit's chemistry. On the other hand, results from Dorling and Rogerson [9] seem to indicate that this degradation is not present in self shielded flux cored wire weld deposits.

Cochrane et al. have also shown that in multirun M.M.A. welds on thick plate made with identical procedures, root impact properties are insensitive to base metal composition. In particular, different elements which promote precipitation strengthening, such as Nb or V, do not seem to have a detrimental effect on weld metal toughness. On the other hand, Fick and Rogerson [10] have shown that in submerged arc deposits root run toughness is affected by base metal composition, but this is probably due to the high dilution, which is characteristic to the process.
The foregoing results stress the importance of undertaking a systematic study of the factors that may have an influence on dynamic strain ageing of weld deposits produced with those consumables frequently employed in structural steel work.

EXPERIMENTAL PROCEDURE

Two cellulosic, one basic iron powder covered electrode, and two CO₂ shielded basic flux cored wires were used in this work. AWS type designations and typical all weld metal analyses along with the chemical composition of the base plate, are indicated in table I.

In order to study the intrinsic susceptibility to dynamic strain ageing of the consumables used in this work, some experimental procedure that might allow to introduce in a weld a controlled degree of deformation at a fixed temperature was sought for.

A rather simple test was devised, consisting in a single run deposited on a 9 mm. thick low carbon steel plate (weld preparation "A", fig. 1). In this test a single plate with a machined 70 degree V-groove preparation was used and a single run weld was deposited. Thus, the deposit was free from the effects of strain ageing produced by subsequent runs.

A longitudinal tensile specimen was then cut out as indicated in Fig. 1 and plastically deformed 6.5% at 250° C in a 40 Ton capacity tensile testing machine at a strain rate of 10⁻⁴ 1/sec. The 6.5% value of deformation was selected to reproduce what is thought to be a reasonable upper bound for the plastic deformation at the root of a multipass weld in thick plate. Heating of the specimen was achieved by means of two flat resistance heaters specially built for this purpose. Temperature was controlled inserting thermocouples at different places of the specimen and recording the output during the test. Homogeneity of deformation was checked inscribing a square grid on the specimen and measuring it after the test at several points.

Standard subsize (5 mm X 10 mm) charpy type specimens were machined out of the tensile specimen, as shown in Fig. 1. The notch depth was 2 mm in all cases. An identical weld was prepared without strain ageing and used as reference for each consumable. Impact testing was then performed at -40, -20, 0, 20, 60° C.

To study the influence of dilution on the modification of impact properties promoted by dynamic strain ageing, a similar set of samples was made using weld preparation "B" of Fig. 1. In this case the weld bead was deposited on an all weld metal base, pre-
FIG 2. Absorbed energy in Charpy-V tests (prep.A)
Fig 3—Absorbed energy in Charpy-V tests (prep. [3])
viously prepared using the same electrode that was going to be tested. This allowed to eliminate the influence of the base plate on weld metal composition.

It is worth noting that with this weld preparation, it was found impossible to impose a 6.5% plastic deformation to the weld deposit corresponding to electrode E 100 T. The reason for this being the marked increase in yield stress during deformation, produced by strain ageing. In this case the sample was loaded only up to 2% plastic deformation.

To determine the influence of nitrogen level in the weld bead on the susceptibility to dynamic strain ageing, one sample was prepared using the E 7018 electrode and weld preparation “B”, shielding the arc with an Argon flow during welding.

RESULTS AND DISCUSSION

The absorbed energy in the impact testing of subsize Charpy-V specimens, obtained from welds corresponding to preparation “A”, is given in Fig. 2. Results corresponding to weld preparation “B” are shown in Fig. 3. Fig. 3.3 shows the results obtained with the Argon shielded weld.

These results indicate that all the consumables tested in this work are highly susceptible to dynamic strain ageing. The plain C-Mn deposits corresponding to electrodes E 7018 and E 70 T-5, with a relatively high manganese content, exhibited the best impact values in the strain aged condition.

Dilution has no significant effect on notch toughness of strain aged material, as can be seen from a comparison of Fig. 2 and 3. On the other hand, dilution has a variable effect on properties of “as welded” deposits. Absorbed energy values rise with dilution in welds made with the cellulose E 6010 and E 7010 Al electrodes, and with the basic E 100 T flux cored wire. The opposite occurs with E 7018 and E 70 T-5 Charpy-V values in the transition temperature range, where the absorbed energy greatly improves with decreasing dilution.

These effects can be partially understood bearing in mind base metal composition (table I), which shows a very low carbon level. Dilution produces a reduction in C content of deposits made with the cellulose electrodes. This does not hold for the basic electrodes E 7018 and E 70 T5, in which case dilution not only does not promote a decrease in C content but also produces a lower Mn content, which would allow for the aforementioned effect. It is not clear so far the effect of dilution in the deposits made with the flux cored wire E 100 T, which incorporates Niqel and Molibdenium to the weld metal.

Fig. 3-5 shows that the effect of strain ageing is fully developed with amounts of plastic deformation as low as 1% and 2%. In Fig. 3.3 the effect of Argon shielding on strain ageing susceptibility of E 7018 weld deposits is apparent. This may be ascribed to the reduction of nitrogen levels in the weld bead (table II), as compared to the weld made without inner gas shielding.

The results hitherto indicated seem to confirm the findings of Cochrane et al [2], in the sense that notch toughness at the root region of multipass M.M.A. welds in thick plate are insensitive to electrode composition and degree of dilution, and that dynamic strain ageing may be the controlling factor.

Toughness degradation at the root, due to dynamic strain ageing, seems the result of a complex interrelationship between N content, flow stress values at high temperature and substitutional solute types and levels. In particular, it is possible that strain ageing at the root of multipass welds be controlled by high temperature base metal to weld metal flow stress ratio, which would influence the amount of plastic deformation at the weld root. This may account for the results from Dorling and Rogerson [9], who failed to detect a significant reduction in notch toughness at the root when compared to the subsurface region in multipass self shielded flux cored wire welds.

CONCLUSIONS

All the consumables used in this work proved to be highly susceptible to dynamic strain ageing under 6.5% plastic deformation at 250° C. In this case, plain C-Mn basic consumables E 7018 covered electrode and E 70 T-5 flux cored wire were the least affected as judged from impact testing, thus stressing the beneficial influence of a relatively high manganese level.

Under severe strain ageing conditions, dilution has no significant effect on toughness degradation of the deposits.

Use of inner gas shielding to reduce N level in the weld deposits leads to an improvement in toughness of strain aged material, thus stressing the role of this element in dynamic strain ageing.

Dynamic strain ageing effects are fully developed with plastic deformation values as low as 1%.

Dynamic strain ageing effects seem to be the result of a complex interrelationship between N content, flow stress values at high temperature and substitutional solute types and levels.

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