# Control of M M A Weldmetal Notch Toughness

by R. JOHN*

***Synopsis : The subject of weld metal toughness with respect to manual metalic arc welding is discussed. The main features to be reviewed are the interacting influences of welding procedure and weld composition, relative to surface and root properties.***

## Introduction

One of the primary problems facing the designers of load carrying structures is the prospect of catastrophic failure through brittle fracture. The problem is particularly acute if joint thicknesses are high, if service temperatures are low or if stress concentrating geometries are employed.

In the early days of arc welding, brittle fracture of welded joints produced many spectacular failures. Consequently, today, most design codes throughout the world carry requirements for the measurement of toughness usually by the charpy impact test. Impact test requirements have been derived empirically either by comparison with service experience or by correlation with larger scale tests such as the wide plate test. Over the past ten years, quite a number of changes have taken place, which have influenced the nature and severity of weld metal toughness requirements. In the UK the changes which have occured may be summarised as:—

(i) The development of high strength micro-alloyed, carbon manganese and low alloy steels has led to the fact that no longer can weld metal be protected by a significantly higher strength relative to the plate material.

(ii) The need to design and build thick walled oil production platforms for the North Sea has led to new demands on the weld metal from the conflicting viewpoints of toughness and production efficiency.

(iii) Increased Government legistlation in the health and safety field has led to a more conservative approach by designers because liability for poor design is now personal as well as corporate.

As a result of these trends, the demands on weld-metal toughness have increased drastically. The object of this paper is to review the relationship between consumable design and welding procedure so that the factors which influence weld metal toughness are better understood and the increased levels more readily achieved. The paper is confined to manual metal arc welding with lime fluospar coated electrodes although many of the observations made are applicable to other processes. Three main factors are to be examined with respect to weld-metal toughness.

1. The influence of the welding procedure.
2. The influence of weld-metal composition.
3. The behaviour of the root in thick joints.

## Welding Procedure

Fig. 1 shows the influence of heat input on impact behaviour.

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* BOC MUREX, U. K. Paper presented at Afro-Asian Conference on Welding & Metals technology in New Delhi in February 1978.

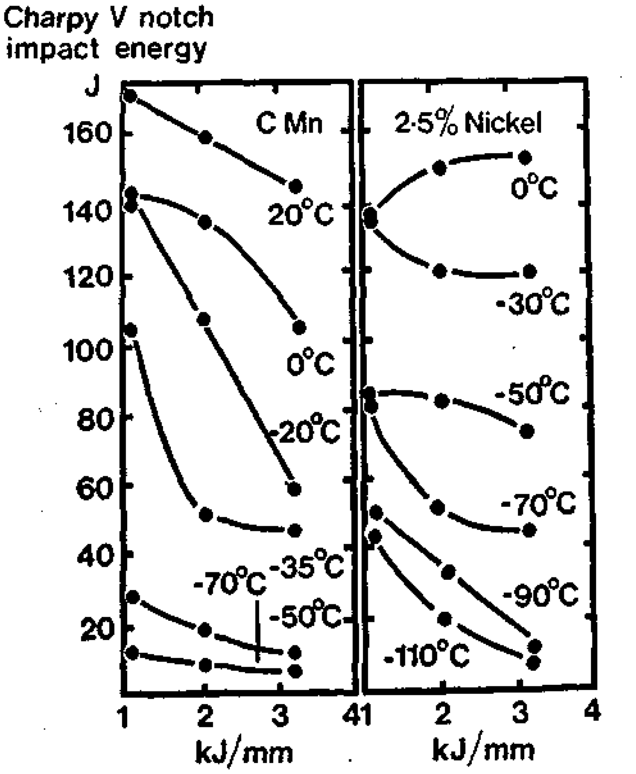

Fig 1 Effect of heat input on impact energy

The studies reported were carried out using 4 mm basic coated electrodes to produce welds in the flat position in 19 mm thick carbon manganese steel plate using an 'all weld' preparation as specified in BS 639. The effect of heat input was investigated for two electrode types, one a carbon manganese and the other a ferritic nickel bearing, at a series of heat inputs in the range 1-4 kJ/mm. Test results in the as-welded condition are illustrated in Fig. 1.

Although the magnitude of the effect varied from one electrode to another, the general trend was to raise the 'transition temperature' so that, at temperatures in the transition range, the best impact properties were obtained with low heat inputs.

In practice, the heat input was varied by changing the run-out length per electrode so the longest run-out lengths produced the best charpy V notch values. Heat input was calculated from the formula:

$$\text{Heat input (kJ/mm)} = \frac{\text{V.A. } 60}{1000 \text{ Ws}}$$

where V = Voltage
A = Amperage
Ws = Welding speed in mm/min

It can be seen that the higher the heat input, the lower is the impact energy. Weld-metal is heterogenous in composition in micro-structure. Therefore one of the major problems encountered in procedure testing is the scatter in the results obtained. Fig. 2 shows the variation in scatter which is observed in nickel bearing and carbon manganese weld metals. The top of the band relates to low heat input and the bottom of band relates to high heat input. It should be noted that nickel bearing weld metal reveals much less scatter for temperatures in the transition zone.

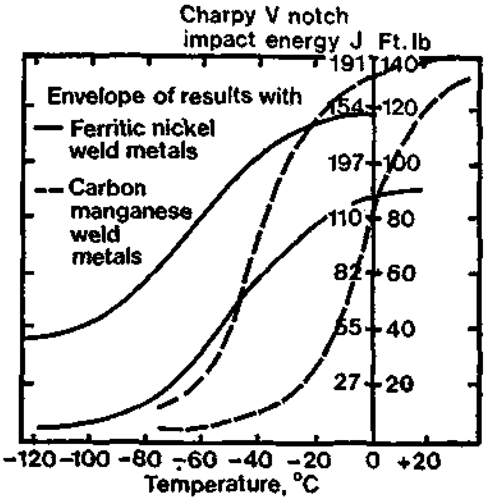

Fig 2 The effect of heat input on transition behaviour

These observations on heat input have led to many welding procedures specifying heat input limitations expressed in kJ/mm. This is effective for welding procedures such as the down hand, horizontal vertical, or overhead where a stringer bead technique is also conducive to good practice from the weldability viewpoint. However, stringer bead welding in the vertical position is not always possible, since this technique can often lead to unacceptable bead profile and slag entrapment. To solve this problem, welders often adopt one of two techniques: wide weave welding or block welding. Wide weave welding generally results in good toughness in spite of a seemingly high heat input, if this is calculated in kJ/mm, whereas block welding with a triangular weave can lead to extremely poor toughness, (*Fig. 3*). After all, one is attempting to induce fairly rapid cooling through the solidification and transformation stages, and maximum grain refinement.

Practically, the rule to remember is that large weld beads are to be avoided if good toughness is to be achieved.

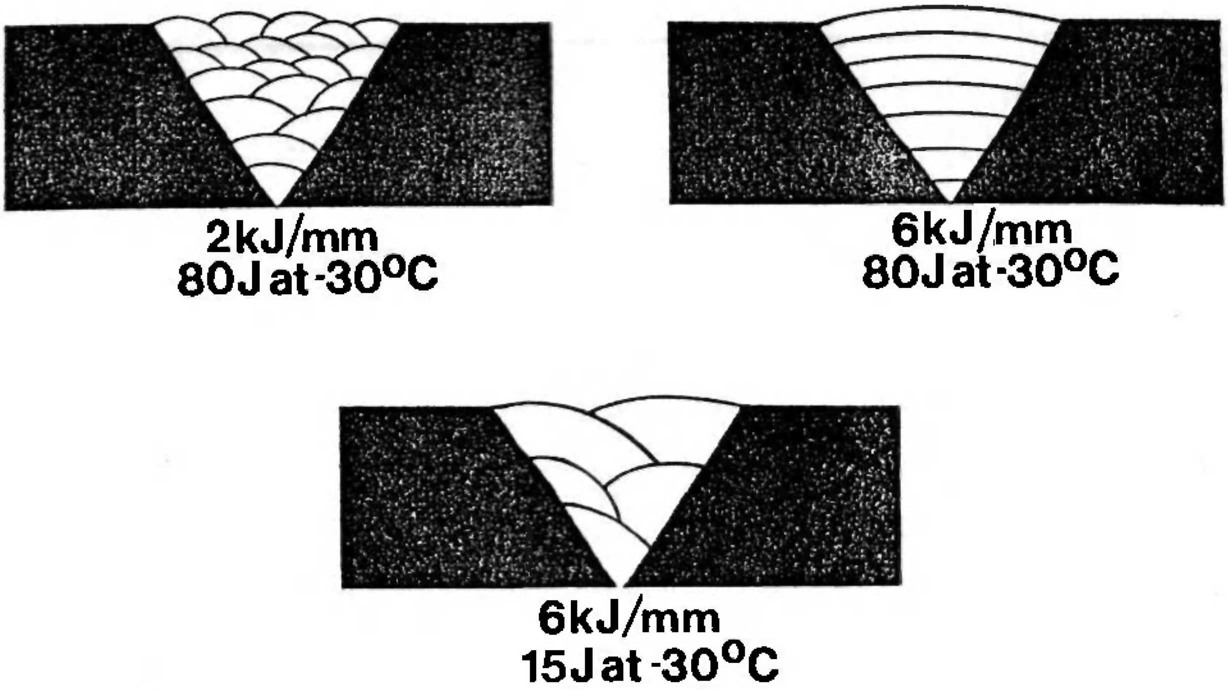

Fig 3 Effect of bead shape on impact performance

**Weld Metal Composition**

Resistance to cleavage fracture is influenced by micro-structure and grain size. The optimum being small grain size and a high percentage of acicular ferrite in the deposited metal. Two of the main elements which promote hardenability are manganese and nickel. For a constant cooling rate increasing amounts of these elements promote increasing amounts of acicular ferrite and therefore good toughness. Fig. 4 illustrates the effectiveness of two elements. It can be seen that nickel is much more effective in promoting low temperature toughness. Other elements can contribute to toughness behaviour in different ways. The influence of silicon for example, is to promote solid solution hardening, increasing strength but detracting from toughness. This is particularly evident in the 2% nickel system as illustrated in Fig. 5. It should be noted that low silicon deposits provided by manual metal arc welding can often exhibit inferior slag detachability unless consumables are carefully formulated.

Ductile fracture by micro void coalescence is influenced by inclusion content and distribution. For this reason, it is important to keep trace elements such as sulphur and phosphorus as low as possible. Inclusion content is often related to oxygen level. Weld metal deposited with basic coated electrodes are generally low in oxygen whereas the weld-metal deposited with rutile or cellulosic coated electrodes are generally high in oxygen. Fig. 6 and 7 illustrate the adverse effect of oxygen on weld metal toughness. The data are taken from the work reported by Tait and Hadrill (ref 4) although these authors did not present it in this form.

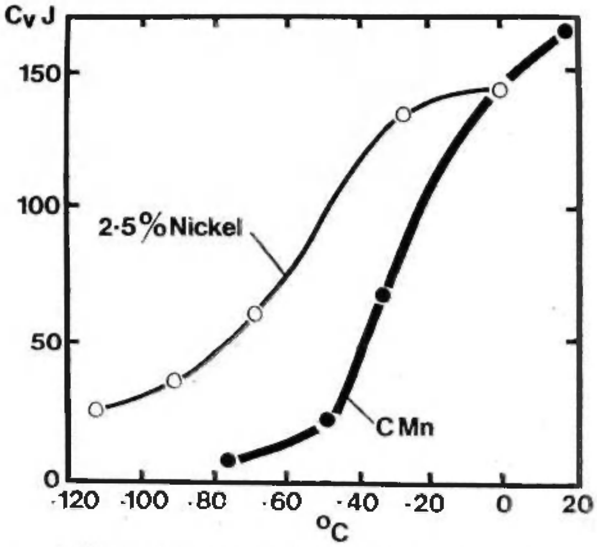

Fig 4 Effect of temperature on impact energy (regression values at 2kJ/mm)

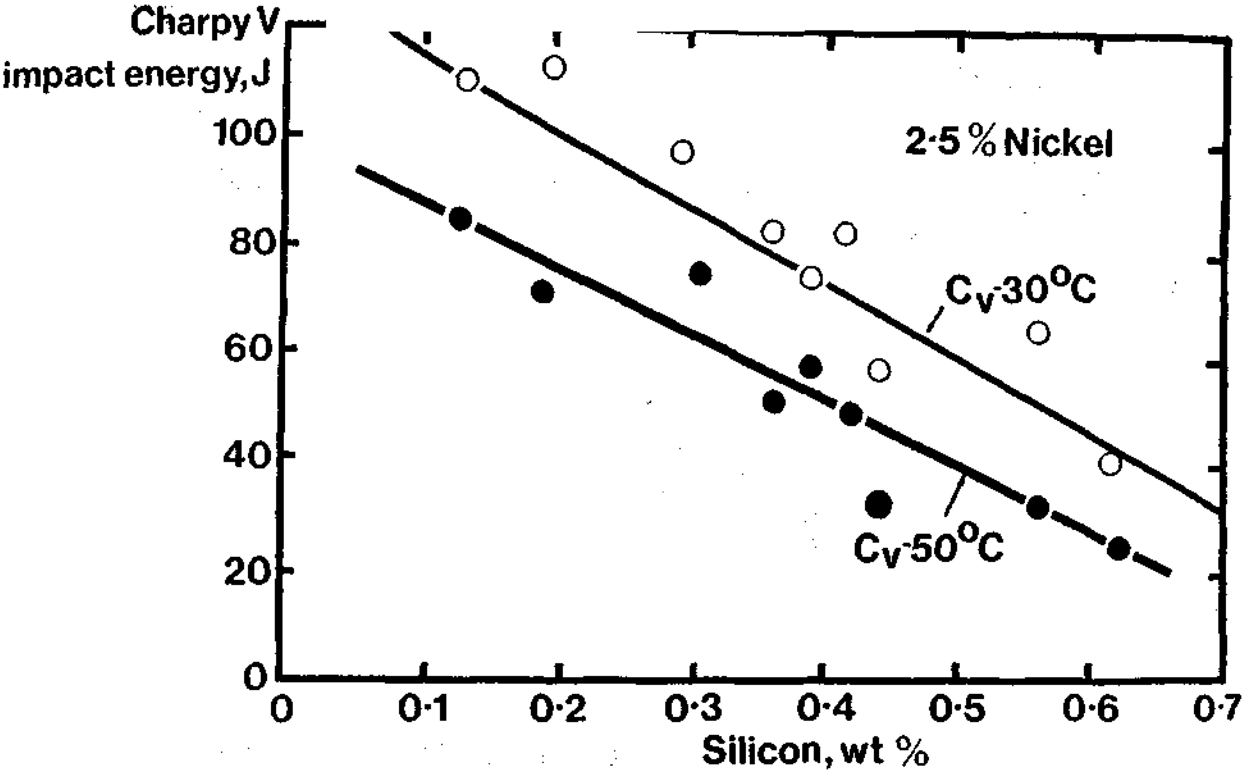

**Fig 5 Effect of silicon on Charpy V impact energy**

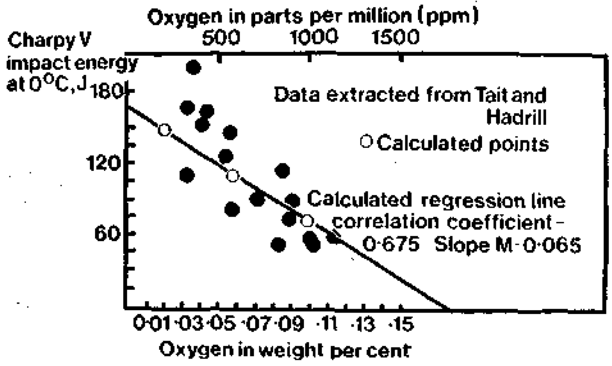

Fig 6 The effect of oxygen on Charpy-V impact energy in MMA weld deposit

## Root Behaviour

On the evidence presented thus far, it would be reasonable to assume that good weld metal toughness may be controlled by selection of the best consumables and optimisation of welding procedure. It is disconcerting therefore to find that if charpy specimens are taken from a thick joint, as illustrated in Fig. 8, then gross deterioration can occur. Fig. 9 demonstrates this behaviour in an 80 mm joint deposited with carbon manganese consumables; the joint was in stress relieved condition. This poor root toughness not only leads to failure if root charpy tests are specified but can also adversely influence performance in COD tests where the root does not lie on the edge of the test piece. Root deterioration is generally thought to be strain age induced with carbon and nitrogen playing important roles. Through dilution, the carbon level in the root of a thick joint in a structural or pressure vessel steel can be double that of undiluted weld metal.

The purpose of the set of experiments described in this section was to determine the effect of weld metal dilution (with plate material) on the performance of the root region.

In each test, welding was carried out on 38 mm thick steel using a $\frac{2}{3}$—$\frac{1}{3}$ double V preparation. Charpy V impact tests specimens were taken from the root of the weld and from near the surface ($\frac{2}{3}$ side) and tested at 0, 20, and —50 °C. Results were recorded by both the as-welded and stress relieved conditions. Welding procedures, pre-heat and interpass temperatures were maintained constant.

Fig. 10 compares root charpy deterioration behaviour for ferritic nickel bearing and carbon manganese weld metals deposited in heavily buttered preparations. The relative performance of the root region is expressed by the surface minus root parameter, which is derived by subtracting each root specimen charpy V notch value

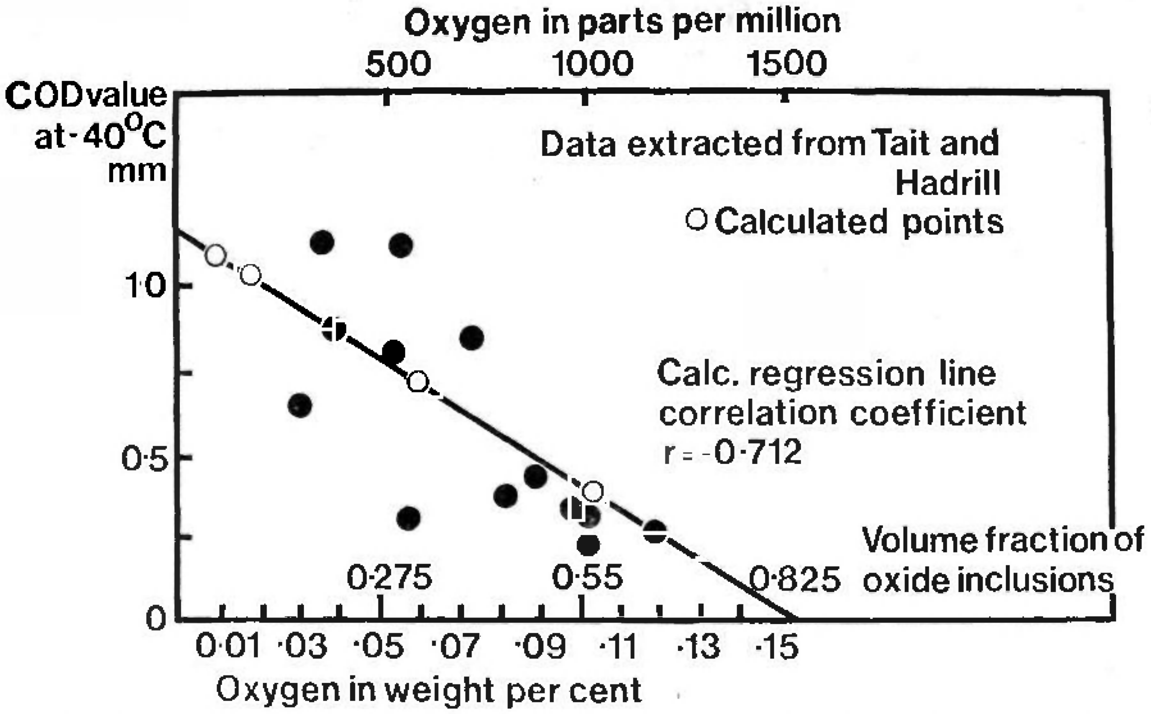

Fig 7 The effect of oxygen on COD value in MMA mild steel weld deposits

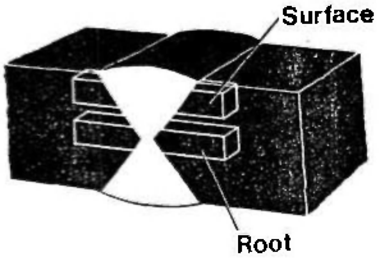

Fig 8 Position of root and surface Charpy specimens

from the value recorded for the equivalent specimen taken 2 mm below the weld surface. Examination of this figure shows that no deterioration of root properties has occured. Since no root deterioration was observed a further two ferritic nickel bearing welds were produced in plate conforming to BS 4360 50D. One weld received only a light grind in the root whereas the other minimised the effect of dilution by heavy arc air back-gouging. Fig. 11 compares the effectiveness of the two treatments against the behaviour of the buttered joint.

It is important to note that the influence of buttering varies from one consumable to another. With the particular consumables used in this experiment, elimination of dilution was sufficient to remove any problem. With other consumables, perhaps nitrogen is less adequately catered for and gross deterioration can persist even after buttering.

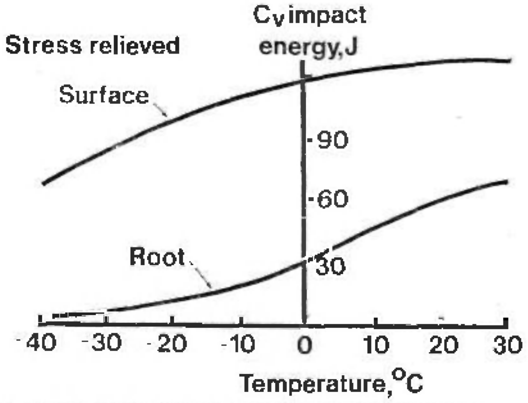

Fig 9 Root deterioration in 80mm thick joint

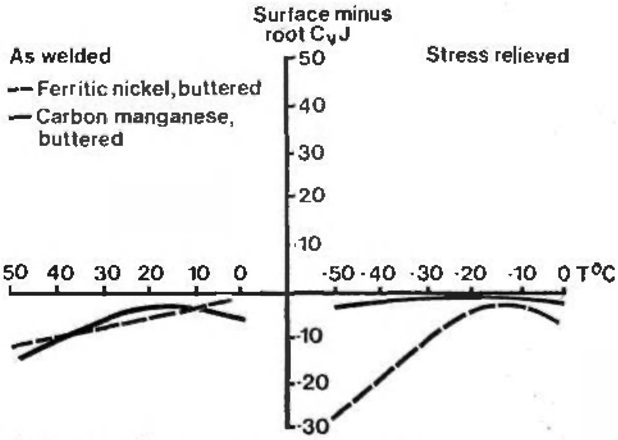

Fig 10 Root Charpy behaviour in 38mm thick joints

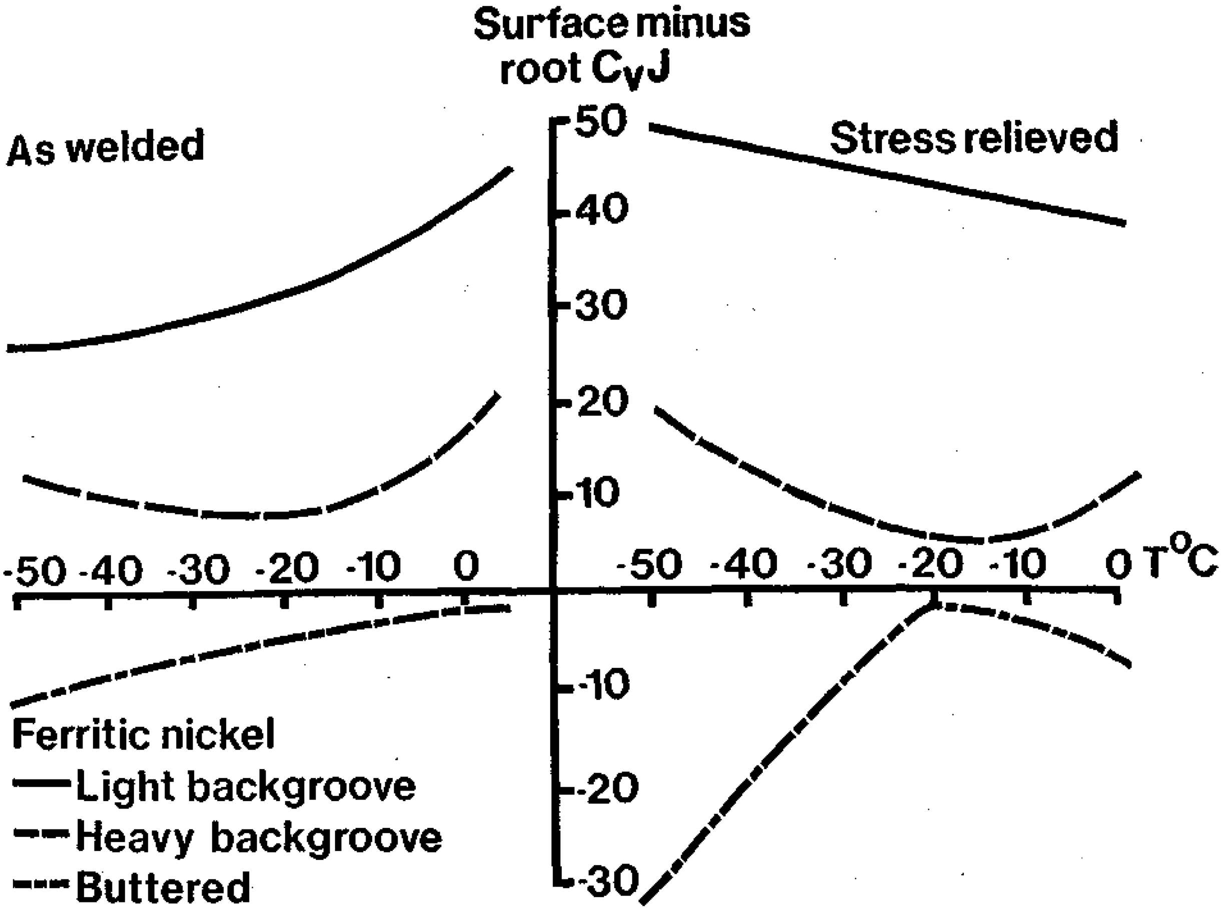

Fig 11 The effect of dilution on root Charpy deterioration

The most practical solution is backgouging, since this removes diluted material and prevents atmospheric incursion from the back of the weld pool. To illustrate this, the following experiment was conducted. A 38 mm thick joint with a double V preparation was welded with carbon manganese consumable. Half of the joint was backgouged and the other half was given a light grind. Fig. 12 shows macro sections taken from the backgouged and non-backgouged section of the joint.

When the histogram of root charpy behaviour at —30°C along the length of the joint is examined (Fig. 13) it can be seen that backgouging has had a very significant effect, (ref 5).

One further practical point should be made to fabricators. Engineers engaged in procedure testing often allow angular distortion of the joint to occur on the assumption that residual stresses will be reduced.

This may be so, but the microstructural damage which can occur in the weld metal will often adversely influence toughness. For this reason, all procedure tests should be carried out under full restraint.

In discussing deterioration, the pick-up of micro alloying such as niobium and vanadium from the plate has not been considered. Fig. 14 illustrates the disastrous effect that niobium pick-up can have in weld metal. This should serve as a warning to steel manufacturers that attempts to increase niobium levels in the search for low carbon equivalent steels could have dire repurcussions on weld metal toughness.

**Conclusions**

Remarks in this paper have been confined to the charpy impact test, and some of the important control parameters related to this test have been examined.

Although there is no direct correlation between charpy impact testing and COD testing, experience at BOC MUREX has shown that the factors discussed in this paper which improve performance in the charpy

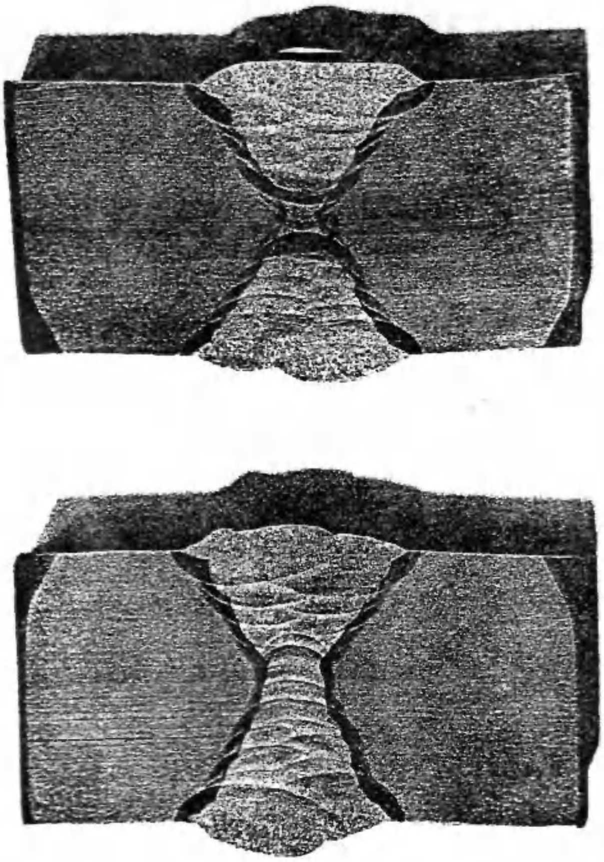

Fig. 12 Macrosections from backgouged (below) non-backgouged (above) regions

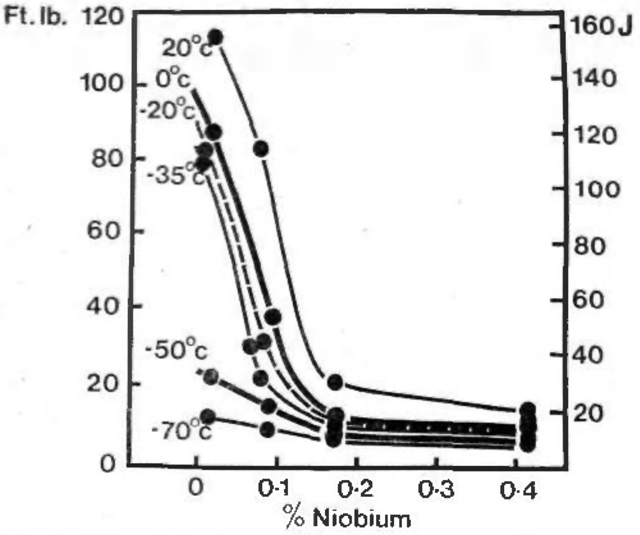

Fig 14 Effect of Niobium on impact properties

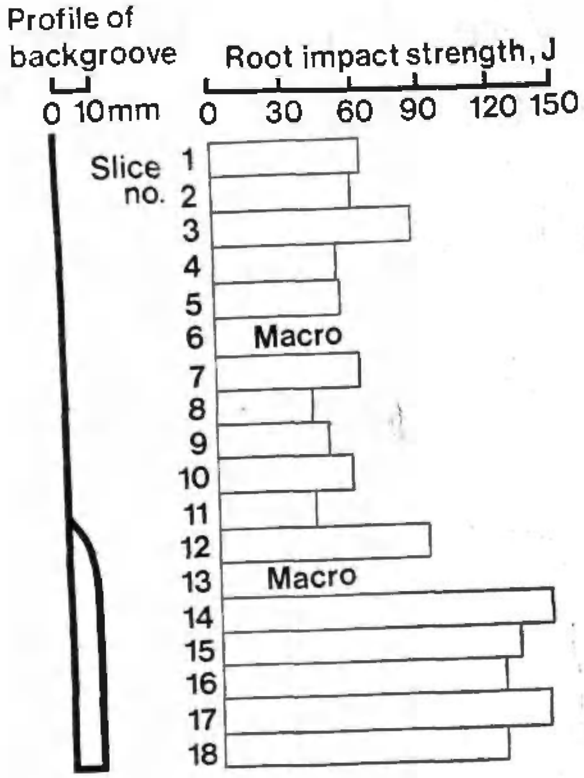

Fig 13 The effect of backgrooving on weld root toughness

test, also improve performance in fractural mechanical tests such as the COD test.

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