WELDS OF STAINLESS STEEL'S TOUGHNESS AND STRENGTHENS

Samir Milad Elsariti
School Of Materials Engineering,
Kompleks Pusat Pengajian Jejawi 2,
Universiti Malaysia Perlis (Unimap), Taman Muhibbah, 02600 Jejawi, Arau, Perlis
Email: samir.elsariti@gmail.com, Tel: 017-6057157

Mohd Nazree
School Of Materials Engineering,
Kompleks Pusat Pengajian Jejawi 2, Universiti Malaysia Perlis (Unimap),
Taman Muhibbah, 02600 Jejawi, Arau, Perlis

ABSTRACT

There are many steels which are stronger than 2000MPa with toughness values exceeding 100MPa and which have been in market for many years. It is well known that the toughness of stainless steels or welds of stainless steel decreases due its high strengthens. So, it's common to add nickel to a stainless steel in order to enhance toughness. By our calculation shows that nickel won't improve toughness in case of availability of high concentration of manganese. A variety of experimental and theoretical approaches towards stronger weld metals are assessed here. And we predicted that nickel only enhance toughness in case of manganese is low concentrated. We have done some studies using x-ray diffraction and micro-structure by scanning electron microscopy. Those studies show as expected that's nickel and manganese with high or low concentration affected the mechanism of toughness in a stainless steel and its welds.

Keywords: stainless steels, welds, toughness, strengthens.

Introduction

Stainless steel has the major disadvantage that it experiences a yielding breakable transition at low temperature or high strain rates (Laslie, 1981). The cracking mode changes from one involving significant deformation to cleavage as shown in the next figure. This is because the flow stress of stainless steel is very sensitive to temperature and eventually becomes larger than necessary to cleavage the crystals (Murugananth, 2002). In the research of weld metals, done by Lord concentrated on improving the toughness of a nickel containing commercial steel weld electrode OK 75.78 as shown in the Table 1, used for applications where toughness is critical (Lord, 1998).

Figure 1: Diagram of showing the yielding brittle transition in stainless steel weld

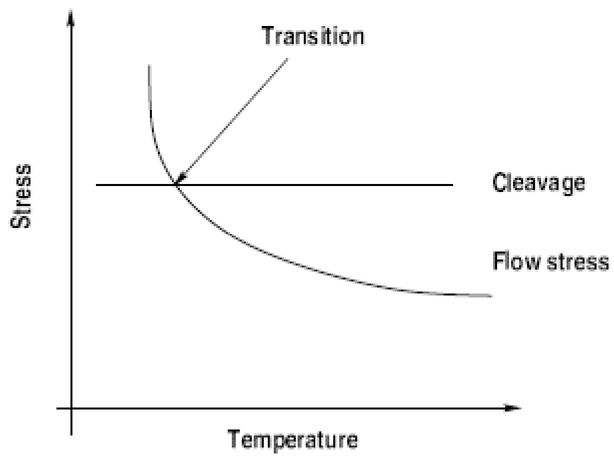
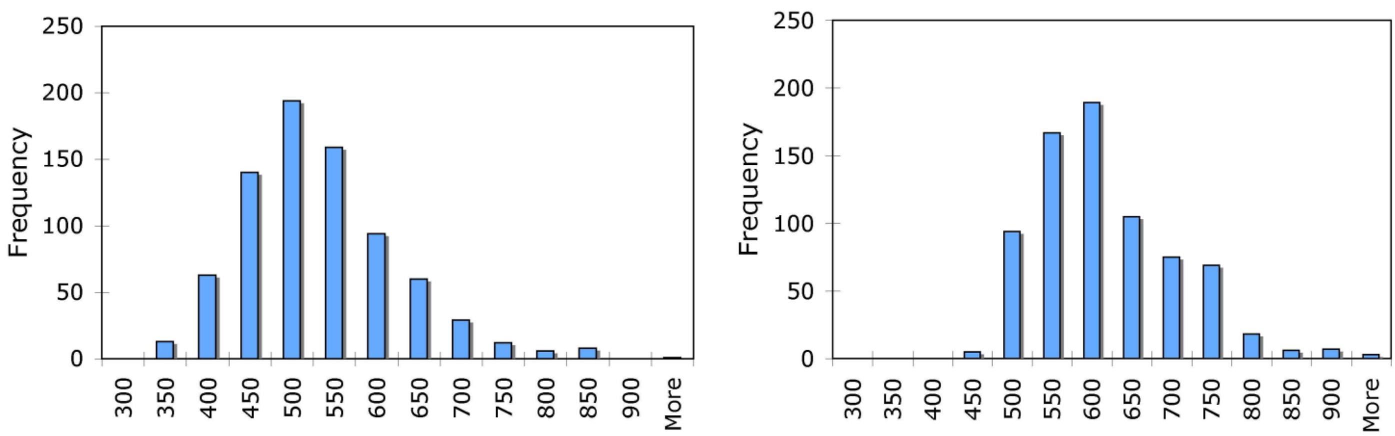


Table 1: Typical composition of commercial welding electrod OK 75.78 in wt%

C	Mn	Si	P	S	Cr	Ni	Mo
0.05	2	0.3	0.005	0.012	0.5	3	0.6

The concentration of solutes added to steel weld metals must be minimised in order to ensure toughness so that the welded structure can resist both residual and imposed stresses without the risk of brittle crack. Weld metal yield strengths therefore usually are in the range 350 to 550 MPa, with infrequent higher values achieved at the expense of toughness, as in Figure 1. The microstructure of such weld metals consists of mixtures of allotriomorphic steel (α), austenite steel (α_w), acicular steel (α_a) and the so known as microphases which small quantities of retained austenite and martensite (Chang, 1996). Allotriomorphic steel is weak, and steel weld suffers from poor toughness. This leaves acicular ferrite as a good strengthener which also has the ability to frequently deflect cracks; its fraction in the microstructure should therefore be as large as possible (Kalish, 1970). The total strength of a single–pass weld consists of influences from the basic strength of pure iron, solid solution strengthening and microstructural contributions from the variety of phases. This last component is only 27 MPa when the fraction of allotriomorphic steel is

Fig. 2: Distribution of strength in ferritic steel weld metals. (a) Yield strength, 779 welds. (b)Ultimate tensile strength, 734 welds. Data from.



(a) **(b)**

V_ = 1, 486 MPa when V_w = 1 and 406 MPa when V_a = 1. Since the intrinsic strength of pure iron is about 220 MPa at ambient temperature, and since the ability to solid solution strengthen is limited by hardenability considerations, it is not surprising that the vast majority of welds based on these microstructures have strength in the range quoted above. Figure 2 shows that there are few alloys which exceed a yield strength of 700 MPa. The term of high strength is therefore used for welds whose yield strength go above 700 MPa.

Abnormalities From Predictable Microstructures

To achieve even greater strength, it is necessary to suppress transformations to lower temperatures. This makes greater nucleation rates and leads to a improvement of microstructure.

It also becomes possible to obtain phases such as lower bainite and martensite. Martensite is traditionally avoided because of its link with poor toughness in welds, but it should be recognised that not all martensite is brittle even in the untempered form. Instead, we shall see that embrittlement is more to do with poor alloy design so martensite need not be avoided in an effort to make stronger weld metals. Consider the classic case of welding alloys used in the manufacture of submarines which have high–strength tempered martensitic hulls. These typically have the composition selected H1 in Table 2, with a microstructure that is a mixture of bainite and martensite (Keehan, 2006). The carbon concentration is kept low, at a value not much greater than the maximum solubility in ferrite. Although the concentration exceeds the solubility, it is well known that excess carbon is surrounded at defects in the bainite and martensite, to such an extent that the effective solubility is almost the same as the total concentration. It is possible in these circumstances, to completely avoid cementite precipitation. To conclude, low carbon martensite need not be brittle indeed, commercial welding alloys based on H1 composition are strong and tough.

Unsuccessful attempts have been madeto go beyond H1, by increasing the nickel concentration. Figure 3 proves the problem, that seeming increases in toughness for example weld H5, were really associated with dramatic reductions in strength.

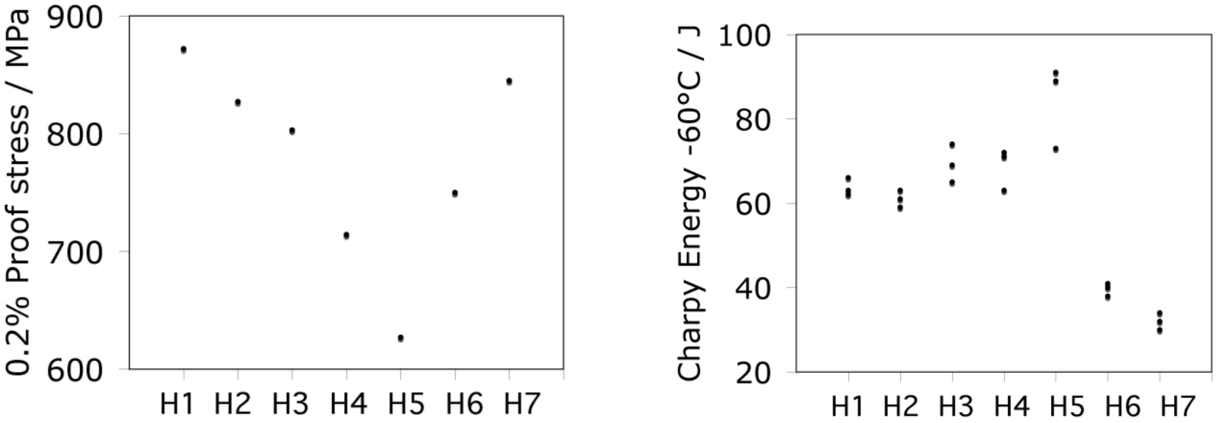
The work described above was based partly on the prevailing opinion that the addition of nickel to ferrite leads to an improvement in the toughness. The mechanism for this is not clear but it is possible that nickel improves the ability of dislocations in steel to slide more easily, thereby making yielding failure more likely than cleavage. The centers of dislocations in steel can be made-up to be three dimensionally dissociated and nickel causes them to tighten, leading to reduction in flow stress (Murugananth, 2002).

Table 2: Approximate compositions of a series of weld metals.

	H1	H2	H3	H4	H5	H6	H7

C wt%	0.05	0.02	0.05	0.02	0.02	0.02	0.10
Mn	2.0	2.0	1.0	1.0	1.0	1.0	2.0
Si	0.30	0.30	0.30	0.30	0.30	0.30	1.75
Cr	0.45	0.45	0.45	0.45	0.00	0.00	0.00
Ni	3.0	3.0	4.0	4.0	4.0	4.0	2.0
Mo	0.6	0.6	0.6	0.6	0.6	0.6	0.2
Cu						2.0	

Figure 3: The strength and toughness of the welds listed in Table 2.



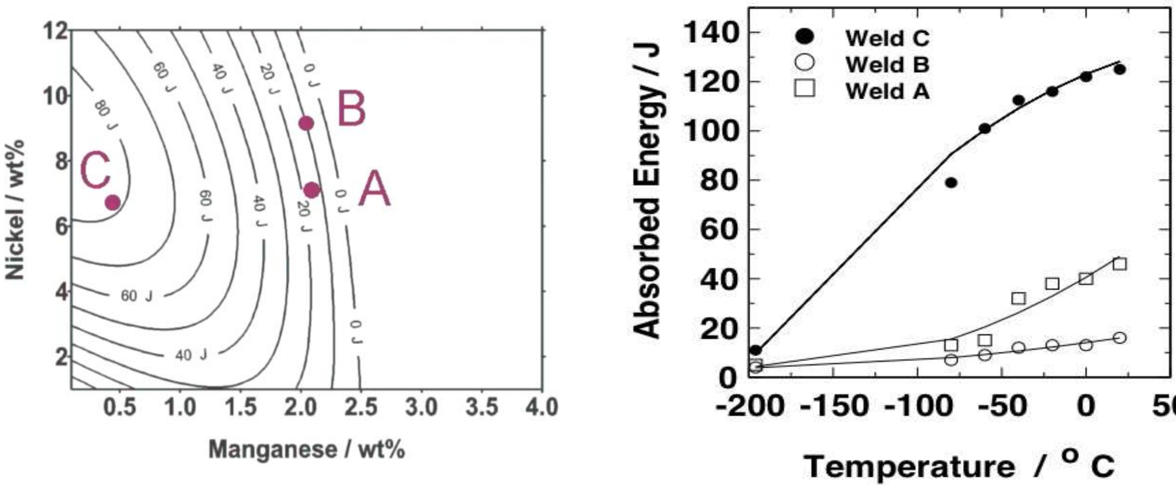
Whereas the beneficial effect of nickel may have been verified in specific alloy systems such as steels used for cryogenic applications, it is clear from Figure 2 that it does not always lead to better toughness in high strength weld metals. We have seen that relative to a well recognized strong, commercial manual metal arc welding electrode H1, from Table 2, an increase in the nickel concentration actually leads to corrosion in the Charpy energy (Keehan, 2006).

Some researchers compiled a neural network model which led to the discovery that in strong weld metals, nickel is only effective in increasing toughness when the manganese concentration is small. This is shown in Figure 4, where the contour plot shows the impact energy at −60 ◦C for welds A (7Ni–2Mn), B (9Ni 2Mn) and C (7Ni-0.5Mn); the details are described elsewhere. Experiments validated the neural network predictions so fundamental works was commenced to understand the mechanism of the Ni–Mn phenomenon.

Combined Bainite

The mechanism by which a combination of high manganese and nickel concentrations leads to corrosion in strength has been studied in detail. It appears that when the transformation temperatures are sufficiently suppressed, such that there is only a narrow gap between the bainite and martensite–start temperatures, a coarse phase labelled coalesced bainite forms.

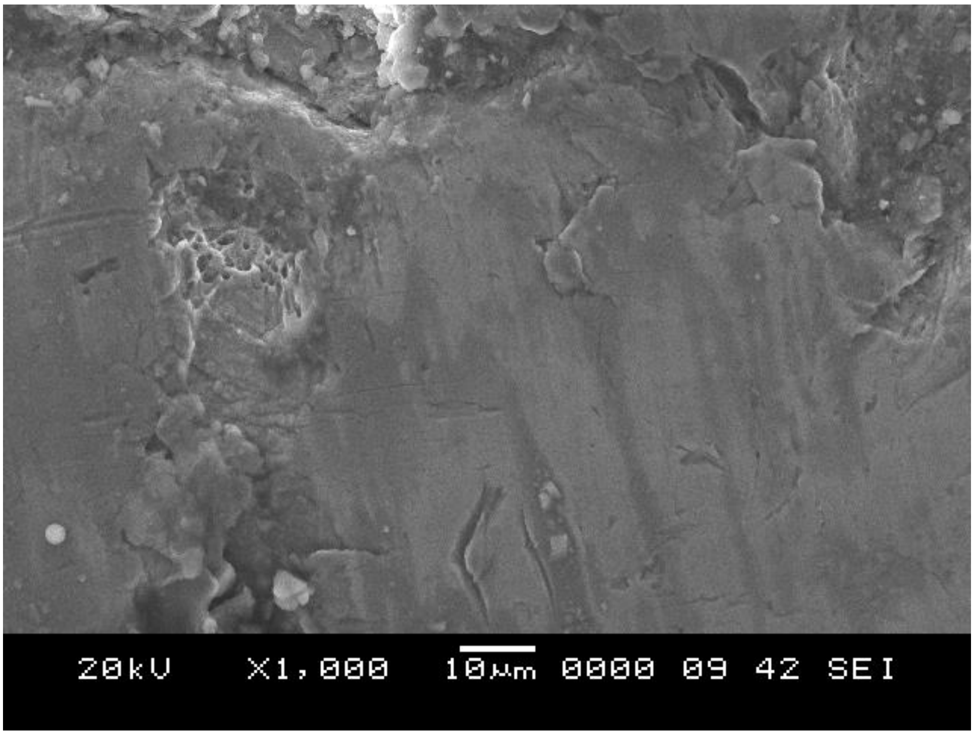
Figure 4: (a) Contours showing the combined effect of manganese and nickel on the calculated toughness for -60◦C, of weld metal produced using arc welding with a heat input of 1 kJmm−1, with a base composition (wt%) 0.034 C, 0.25 Si, 0.008 S, 0.01 P, 0.5 Cr, 0.62 Mo, 0.011 V, 0.04 Cu, 0.038 O, 0.008 Ti, 0.025 N, and an interpass temperature of 250◦C. (b) Full results for welds A, B, and C.



Combined bainite occurs when in line small plate lets of bainite join to form a single larger plate. This striking change in form occurs at large undercoolings. Since together sub units of bainite have an identical crystallographic orientation, they may become one given sufficient driving force to sustain the greater strain energy associated with the coarser plate, and if there is nothing to stifle the lengthening of the sub units. The first condition is satisfied by the large undercooling. The second suggests that combination is only possible at the early stages in the transformation of austenite, when growth can not be slowed down by hard impingement with other areas of bainite.

Experiments have now confirmed that the rough, combined bainite appears in weld metals containing large concentrations of both manganese and nickel, such that the bainite forms at temperatures very close to the martensite–start temperature. It leads to a deterioration in toughness and can be avoided by careful modifications of composition, for example, by reducing the manganese concentration when the nickel concentration is high.

Figure 5: Combined bainite in a 7Ni-2Mn wt% weld metal.



Summary

An important outcome of research on strong welds is that it is not generally true that the addition of nickel to steel weld metals leads to an increase in toughness and strength. Any increase in the nickel concentration must be balanced by a reduction in manganese in order to broaden the difference between the bainite start and martensite start temperatures. Otherwise, a rough phase appears, a result of the combination of plate lets of bainite which are in alike crystallographic orientation.

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