STUDIES ON MICROSTRUCTURAL AND MECHANICAL PROPERTIES
OF SOME AUSTENITIC STAINLESS STEEL WELD METALS

ABSTRACT

Single phase austenitic stainless steel weld metals are prone to hot cracking. To avoid hot cracking, the composition of the filler metal is so adjusted to give 3-10% delta ferrite in the weld metal depending upon the composition of base metal. Duplex stainless steels having ferrite content as high as 40 to 50% are being increasingly used for offshore application due to their better corrosion resistance properties. Therefore, it is important to understand the effect of ferrite content on weld properties when its content is more than 10%.

The austenitic weld metals containing delta ferrite may get exposed to elevated temperatures upto 1200 K either during service or during stress relieving/solution annealing treatments. Delta ferrite, being a metastable phase, either transforms to secondary phases like sigma, carbides etc. or dissolves into austenite matrix. Although many studies on phase transformation of austenitic weld metals have been reported, comparative studies taking initial ferrite content and chemical composition into account are not available.

Most of the researchers concentrated mainly on Mo containing austenitic stainless steels (viz. AISI 316) eventhough other types of stainless steels viz. AISI 304, 321 and 347 are also extensively used in different
industries. Therefore, it is appropriate to study the comparative behaviour of Mo free and Mo containing stainless steels. Also, the initial ferrite contents of most of the studies have been confined to 3 to 6%. Furthermore, not many systematic studies have been carried out on the ferrite variability in the longitudinal, transverse and cross-sectional directions of single pass welds in the as-welded and post weld heat treated (PWHT) conditions.

In view of the above, an experimental programme was undertaken to study the ferrite variability of welds in the longitudinal, transverse and cross-sectional directions and to study the effect of different levels of initial ferrite contents (4FN to 23FN) of Mo containing austenitic weld metals on their microstructural and mechanical properties in as-welded and PWHT conditions and to compare them with Mo free austenitic weld metals. Also, it was planned to study the ferrite decay due to PWHT up to a temperature of 1273K for ageing time up to 100 hrs. by ferrite measurement using magne gauge. Phase transformation studies due to above PWHT were carried out using X-ray diffraction method and optical microscopic examination. For the above programme, austenitic stainless steel plates of 4 mm thickness of type AISI 304 & 316 were welded in a single pass in order to avoid the effect of multipass welding on the ferrite content. 3 different
types of stainless steel electrodes were used to weld AISI 316 plates in order to get 3 different initial ferrite contents viz. 4FN, 10FN & 23FN in the weld metals. The electrodes for welding of AISI 304 stainless steel plates were selected in such a way to get initial ferrite content of 10FN in the weld metal so that its properties can be compared with other Molybdenum containing weld having initial ferrite content of 10FN. Shielded metal arc welding process using direct current electrode positive polarity was used for welding all the plates. After welding, the welds were inspected by dye penetrant inspection and radiographic examination using X-rays. The defective portion was discarded and only defect free portion was used for the study.

The test pads were then subjected to PWHT at 823K, 923K, 1023K and 1273K for ageing time of 1 hr, 10 hrs. and 100 hrs. in a furnace. After heat treatment, the specimens were polished and etched and delta ferrite was measured on the face, root and the sides of the specimens using magne gauge. A number of readings were taken to report the ferrite variability. Optical microscopic studies were undertaken to examine the microstructure and ferrite morphology of the specimens. X-ray diffraction studies were undertaken to identify different phases in the as-welded and PWHT samples.

In order to study mechanical properties of the weld metals, transverse tensile test specimens (full section and reduced section) and Charpy "V" Notch sub-size (V)
impact test specimens were prepared and the tests were carried out at room temperature.

The results on ferrite measurement indicated that the ferrite content varied from point to point in longitudinal, transverse and cross-sectional direction of as-welded and PWHT welds with maximum ferrite content at the centre of the face of weld due to minimum dilution and minimum ferrite content near the fusion lines due to maximum dilution. Less ferrite content was observed at the centre of the root as compared to the face of the weld due to more dilution at the root because of smaller root width. However, ferrite variation in the centre of weld on face and root was found to be within ± 0.1FN (Standard deviation).

Due to post weld heat treatment, the ferrite content was observed to decrease at all places with increase in ageing temperature/time but the variation of delta ferrite of the PWHT welds followed the same trend as for as-welded samples. The decrease in ferrite content i.e. Ferrite Decay was found to depend on initial ferrite content and chemical composition (Mo). Higher initial ferrite resulted in higher percent ferrite decay due to PWHT upto 1023K and lower percent ferrite decay at 1273K PWHT. Further, ferrite decay in Mo containing weld metal (E 309 Mo) was more compared to Mo free weld metal (E 308).

The ferrite in the as-welded samples of low initial
ferrite weld metal was found to have "Vermicular" morphology and that in high ferrite weld metal was of Widmanstatten morphology. After PWHT at 1023 K, the morphology of low ferrite weld metal tended to spheroidise while that in Widmanstatten remained the same. However, after PWHT at 1273K, even the Windmanstatten morphology was found to spheroidise.

X-ray diffraction studies revealed that the transformation of ferrite into sigma phase depended on initial ferrite content and presence/absence of Mo apart from PWHT temperature/time. It was found that ferrite content and Mo enhanced sigma kinetics. In high initial ferrite weld metals, the sigma phase appeared after PWHT at 1023 K for 1 hr. and even after PWHT at 923K after 100 hrs. exposure, whereas in low initial ferrite weld metals, sigma phase was absent in samples PWHT at 923K even upto 100 hrs.

Most of the full section transverse tensile test specimens failed in the base metal indicating that in general, the weld metal was stronger than the base metal. However, some of PWHT samples (full section) containing sigma phase failed in weld metal even without a notch indicating the inherent brittleness of sigma phase. The results on Transverse Tensile testing of reduced sections indicated that initial ferrite content increased yield strength and ultimate tensile strength of the as-welded specimens. For high initial ferrite weld metals, yield strength and ultimate tensile
strength after PWHT at 923 K and 1023 K were found to be more as compared to those with low initial ferrite welds due to the presence of sigma. The weld metals containing Mo were found to have more yield strength and ultimate tensile strength after PWHT at 923 K and 1023 K as compared to Mo free welds. However, tensile strength for all weld metals decreased after PWHT at 1273K irrespective of ferrite content and chemical composition due to softening of weld metal and relieving of internal stresses.

Room temperature Charpy 'V' Notch impact tests indicated that the initial ferrite content did not affect significantly the Charpy "V" notch impact energy of as-welded samples but it affected impact energy of PWHT samples. PWHT at 1023K just for 1 hr made the samples containing high initial ferrite (23FN) so brittle that the impact energy dropped to zero. On comparing samples (E 309 Mo & E 308) having same initial ferrite content, (10FN) after PWHT at 923 K & 1023K, it was found that Mo containing welds showed relatively poorer impact energy compared to Mo free welds indicating the negative role of Mo on toughness at higher temperatures. PWHT at 1273K improved the toughness of all weld metals irrespective of initial ferrite content and chemical composition.

It is recommended that the filler metal for welding austenitic stainless steel material shall be selected such that the as-welded ferrite is less than 10FN.
However, if it is inevitable to have high ferrite content in the weld due to design considerations, it shall be ensured that such welds are not exposed to temperatures more than 823 K during service.