# INFLUENCE OF METALLURGICAL PARAMETERS ON THE FRACTURE TOUGHNESS OF STAINLESS STEEL WELDS

P. Ould*, P. Balladon**

The effect of post-weld heat treatment at 600°C and sensitizing heat treatment at 750°C on the tearing resistance and tensile properties of a type AWS 316L stainless steel weld has been investigated. Relationships between the tensile properties and the fracture toughness are discussed. In the second part of this study metallurgical examinations of two stainless steel welds (of types AWS 316L and 308L) showing very different tearing resistance values have been performed in order to get a better understanding of these tearing resistance behaviours.

## INTRODUCTION

Austenitic stainless steel welds can present variability in fracture toughness properties depending on several parameters such as welding process (Mills (1)), heat treatment and ageing condition (Faure et al. (2)). Stainless steel butt welds of the primary coolant piping in nuclear pressurised water reactor are done by different processes (S.M.A.W., S.A.W. and G.T.A.W.). Furthermore, welds joining the stainless steel piping to the reactor vessel ferritic nozzles are submitted to a post-weld heat treatment around 600°C. In order to evaluate the effect of heat treatment on the fracture toughness and mechanical properties of stainless steel welds, fracture toughness tests have been carried out on type 316L S.A. welds as-welded and after post-weld heat treatment at 600°C or after a sensitizing heat treatment at 750°C.

In a second part of this study, metallurgical examinations have been performed on two stainless steel welds (type 308L S.M.A. weld and type 316 L S.A. weld) showing very different tearing resistance values.

* Framatome, Materials and Technology Department
** Creusot-Loire Industrie, Centre de Recherches des Matériaux du Creusot

## EFFECT OF HEAT TREATMENT ON FRACTURE TOUGHNESS AND MECHANICAL PROPERTIES

### Experimental program

Materials.Two AWS 316L Submerged Arc Welded (S.A.W.) butt welds have been made : V grooved joints 40 mm thick (n° 131) and 80 mm thick (n° 2047) using for the base material type AISI 316L plates. Chemical analyses of the weld metals are given in table 1.

On weld n°131 three metallurgical conditions were investigated : 1) as welded, 2) heat treated 10 hours at 550°C + 16 hours at 610°C, and 3) heat treated 25 hours at 750°C. Heat treatment n° 2 represents the envelope heat treatment that can be applied to the stainless steel weld of the joint between the austenitic piping and the ferritic reactor vessel nozzles of a French nuclear power plant. Heat treatment n°3 was chosen to decrease the toughness in order to obtain a range of different toughness properties.

On weld n° 2047 two metallurgical conditions were investigated : 1) as welded, and 2) heat treated 10 hours at 550°C + 16 hours at 610°C.

TABLE 1 - Chemical composition of the 316L SA welds (weight %)

| N° | C | Mn | Si | S | P | Ni | Cr | Mo | N | O |
|---|---|---|---|---|---|---|---|---|---|---|
| 131 | 0.015 | 1.11 | 0.94 | 0.008 | 0.021 | 12.5 | 17.8 | 2.6 | 0.086 | 0.122 |
| 2047 | 0.015 | 1.12 | 0.84 | 0.004 | 0.012 | 12.3 | 17.8 | 2.7 | 0.076 | 0.136 |

Tensile tests : Tensile tests were performed at 320°C with specimens 5 mm in diameter taken in the transverse orientation (longitudinal axis perpendicular both to the welding direction and to axis of symmetry of the weld).

Fracture toughness. Tearing resistances properties of the stainless steel welds have been determined at 20°C and 300°C with 1T-CT 20% side grooved specimens machined from the joints in such a way that the plane of the machined notch is in plane of symmetry of the joint. Single specimen compliance technique has been used to obtain the tearing resistance curves. The $J_{1C}$ values were determined in accordance with the ASTM standard E813-89.

### Results and discussions.

Tensile properties. The tensile test results in transverse orientation obtained at 320°C for each of the metallurgical conditions are given in table 2.

TABLE 2- Tensile properties of the 316L S.A. welds.

| | | 320°C | | | |
|---|---|---|---|---|---|
| N° | CONDITION | Y.S MPa | U.T.S MPa | E % | R.A % |
| 131 | as welded | 333 | 448 | 18 | 41 |
| 131 | H.T. :~600°C | 302 | 450 | 19 | 48 |
| 131 | H.T. : 750°C | 235 | 440 | 23 | 51 |
| 2047 | as welded | 385 | 464 | 14 | 35 |
| 2047 | H.T. : 600°C | 345 | 486 | 20 | 43 |

It can be noticed that the heat treatments induce a decrease of the 0.2% Yield Strength (Y.S.) and an increase of the elongation (E). The effects on the tensile strength (U.T.S.) is not the same for both heat treatments (H.T.) applied : heat treatments around 600°C increase the U.T.S and heat treatment at 750°C gives U.T.S values similar to those of the "as-welded" weld. The decrease of Yield Strength associated with an increase of the ductility may be explained by some recovery during the heat treatment.

Fracture toughness. The $J_{1C}$ values and the $J_{1mm}$ (value of J on the J-R curve for a total extension of 1 mm) measured at 300°C for the two welds are given in table 3.

TABLE 3-Tearing resistance properties at 300°C of the 316L S.A. welds.

| Weld N° | 131 | 131 | 131 | 2047 | 2047 |
|---|---|---|---|---|---|
| CONDITION | as welded | H.T. : ~600°C | H.T. : 750°C | as welded | H.T. : 600°C |
| $J_{1C}$, kJ/m² | 129 | 94 | 67 | 78 | 78 |
| $J_{1mm}$, kJ/m² | 223 | 176 | 146 | 187 | 160 |

These results show that heat treatment around 600°C slightly reduces the tearing resistance and heat treatment at 750°C significantly decreases the tearing resistance. Figure 1 shows the relationships existing between the tensile properties (Y.S and R.A.) and the $J_{1C}$ values. It can be observed that, for a given weld, the evolution of the Y.S and of the Reduction of Area (R.A.) are relatively well correlated to the $J_{1C}$ values. Moreover, the trend of these correlations seems to be similar for both welds notwithstanding a shift of the tensile properties.

## INFLUENCE OF METALLURGICAL PARAMETERS ON THE FRACTURE TOUGHNESS OF STAINLESS STEEL WELDS

Previous fracture toughness results on type AWS 316L and 308L welds (Ould et al (3)) have shown a large scatter of the tearing resistance values. In order to obtain some explanations of the variation of the tearing resistance values, a metallurgical investigation, object of the present study, has been carried out on two stainless steel welds the tearing resistance of which were significantly different.

Experimental procedure

A type AWS 308L Shielded Metal Arc weld (S.M.A.W.) 70mm thick (N°I) and a type AWS 316L Submerged Arc weld (S.A.W.) 70 mm thick (N°II), both aged during 10000 hours at 400°C have been investigated. The tearing resistance properties at 300°C of these two welds are as follows :
Weld n°I : $J_{1C}$(300°C) = 89kJ/m², dJ/da (300°C) = 77 MPa
Weld n°II : $J_{IC}$ (300°C) = 40kJ/m², dJ/da(300°C) = 55 MPa.

The metallurgical examinations performed consist in the determination of the inclusion distribution (content and sizes). The examinations were done in the vicinity of the rupture surface of the CT specimens.

Histograms of the inclusion distributions are given in figure 2 for the two concerned welds. The analyses have shown the following results: the inclusions are globular, the maximum frequency of inclusion sizes is between 1 and 2 μm², the number of inclusions per mm² is, on average, 3.5 time higher for the weld n° II than for the weld n°I. Mean area of the inclusions of the Weld n°II (≈ 17.3 μm²) is about 40% higher than that of the Weld n°I (≈ 12.2 μm²).

A rough estimate of the volume fraction of inclusion is Nv ≈ 3358/mm³ for the weld n°I and Nv ≈10520/mm³ for the weld n°II.

For the Weld n°I, the inclusions are oxides of different types containing in various proportions the followings elements : Cr, Mn, Ti, Si, Al. In the Weld n°II, the inclusions correspond to only one type of oxide containing Si, Mn, Cr and Al.

Interpretation

Local criteria approachs in the tearing resistance analysis use a critical distance $\Delta a_c$ which is related to the volume fraction of inclusion Nv (i.e.: $\Delta a_c \approx 2Nv^{-1/3}$) and to the critical growth of cavities $(R/Ro)_c$). $(R/Ro)_c$ can be evaluated from $J_{1C}$, $\Delta a_c$, and dJ/da with relationships of Devaux et al (5) :
$J_{1C} = \alpha \,.\, YS \,.\, \Delta a_c \,.\, \ln (R/Ro)_c$. (n°i) and $dJ/da = \beta \,.\, YS \,.\, \ln (R/Ro)_c$. (n°ii).
$\Delta a_c$ issued from the relation $\Delta a_c \approx 2Nv^{-1/3}$ are equal to 0.13 mm for weld n°I and to 0.09 mm for weld n°II. The relationship (ii) applied to the dJ/da values of the two weld gives :
$\ln (R/Ro)c|_{weld\ I} / \ln (R/Ro)c|_{weld\ II} = 1.544$.
This ratio reported in the relationship (ii) gives : $J_{1c}|_{weld\ I} / J_{1c}|_{weld\ II} = 2.02$
This value is very close to the value given by the experimental $J_{1c}$ values. This qualitative demonstration allows to conclude that the variations in the toughness properties are partly due to the inclusion content (relied to $\Delta a_c$) and to the critical growth of cavities (R/Ro) c.

## CONCLUSION

The study on AWS 316L weld heat treated at 750°C and around 600°C has shown that the heat treatments applied decrease the fracture toughness. For a given weld, the evolution of the tearing resistance with the heat treatment is relatively well correlated with the yield strength and the ductility. Metallurgical analysis of two stainless steel welds having different toughness properties shows that differences in the toughness properties can partly be explained by the inclusion content.

## REFERENCES

(1)Mills, W.J., "Fracture Toughness of Stainless Steel Welds," Nineteenth Symposium, ASTM STP 969, Ed., T.A. Cruse, 1988, pp. 330-355

(2) Faure, F., Houssin, B. and Balladon, P." ASM Conference on trends in Welding Research" 1989, pp 14-18.

(3) Ould, P., Balladon, P. and Meyzaud, Y. "Int. Colloquium on Stainless Steel, Mons (Belgium)," 1988.

(4) Devaux, J.C., Mottet, G., Balladon, P., Pellissier Tanon, A. Nuclear Engineering and Design, vol. 105, 1987, pp. 131-138.

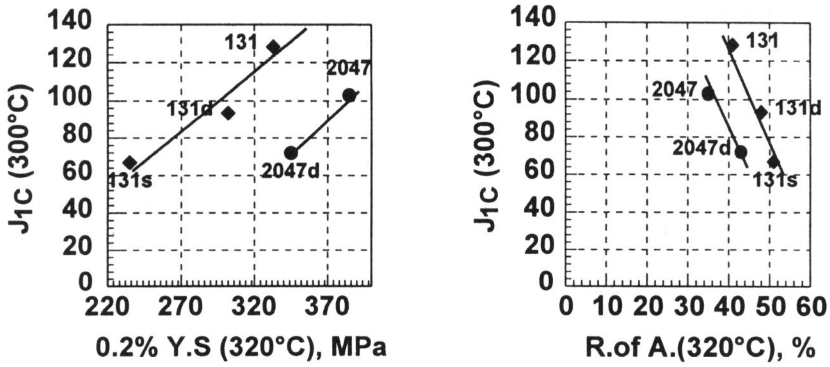


Figure 1 : $J_{1C}$ vs. Yield Strength and $J_{1C}$ vs. Reduction of Area for 316L welds n°2047 and 131 as welded and heat treated (around 600°C (d) and at 750°C (s))

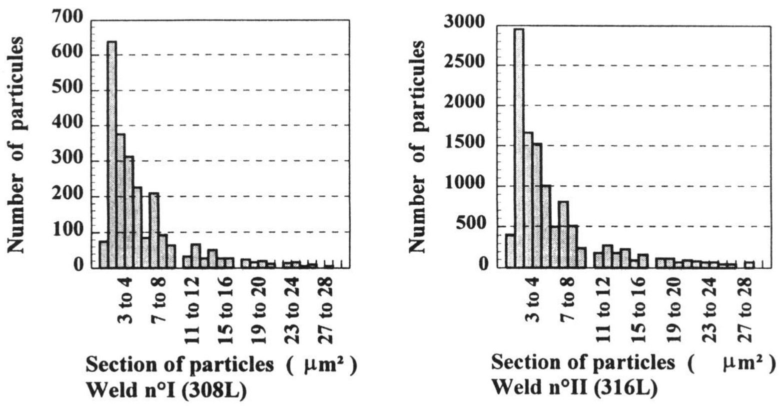


Figure 2 Main parts of the histograms giving the sizes of the inclusions in the stainless steel welds n°I and n°II (somes particules have sizes up to 48 μm²)