

## Effects of Phase Transformations on Residual Stresses in Welding of Stainless Steels

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**In this investigation, we investigate the effects of solid state phase transformation on residual stresses in welding supermartensitic stainless steels, using the Satoh experimental test approach. The results obtained clearly demonstrate that the austenite-to-martensite phase transformation has remarkable effects on the final tensile residual stress level, and stresses as low as 70 to 170 MPa were found, depending on the weld thermal program. These results may imply that unnecessary conservatism is often used when assuming residual stresses to be of the same order as the base metal yield strength.**

### INTRODUCTION

During the last decade, the use of supermartensitic 13% Cr stainless steels has grown in offshore installations (e.g. Enerhaug, 1997, 1999; Olsen, 1999). This allows cost reduction due to much lower material costs than those of alternative duplex grades. Supermartensitic steels also possess a certain corrosion resistance. In some cases, problems have been reported related to the pickup of hydrogen, either from welding (e.g. Rørvik, 1999; Aune, 2003; Akselsen, 2004a) or from the environment (Rogne, 2001, 2002a and b, 2003, 2004). Since their microstructure is mainly martensite, they are in principle susceptible to hydrogen-assisted cracking. Besides the microstructure and hydrogen supply, residual stresses are also important to the risk of hydrogen cracking. The buildup of residual stresses in welding of supermartensitic steels is not very well known. The present investigation was then undertaken to provide information on thermal stresses developed during weld simulation of supermartensitic 13% Cr steel, using the Satoh experimental test. Also included are superduplex 25% Cr and welds made of 13% Cr and between 13 and 25% Cr, both made with superduplex wire. The results obtained will clearly demonstrate that the tensile residual stresses developed in super 13% Cr steels are surprisingly low, and much lower than those of 25% Cr superduplex steel.

### EXPERIMENTAL PROCEDURE

#### Materials

The materials selected for this investigation were supermartensitic 13% Cr steel pipe, superduplex 25% Cr steel pipe, and welds made in 13% Cr steel, and between 13% Cr and 25% Cr pipes, all welded with 25% Cr wires. Details on welding are reported elsewhere (Olden, 2003). Table 1 summarizes the chemical composition of the steel pipes and weld metal (cap). The supermartensitic steel is classified among the high alloyed grade, i.e. of

Material	C	Si	Mn	Cr	Ni	Mo	Cu
13% Cr BM	0.006	0.294	1.87	11.65	6.50	2.33	0.475
25% Cr BM <sup>1</sup>	0.02	0.22	0.56	25.1	6.8	3.8	0.55
25% Cr WM	0.01	0.35	0.42	24.9	8.9	4.0	0.11

<sup>1</sup>with 0.5% W

Table 1 Steel chemical composition (in wt%)

the 12Cr-6.5Ni-2.5Mo type. It contains very low carbon (0.006%), which ensures an excellent weldability.

The room temperature yield and tensile strength for the investigated pipe steels are:

13% Cr martensitic pipe:  $\sigma_{p0.2} = 650$  MPa  $\sigma_{UTS} = 880$  MPa

25% Cr superduplex pipe:  $\sigma_{p0.2} = 595$  MPa  $\sigma_{UTS} = 803$  MPa

#### Weld Simulation

Satoh test specimens (Satoh, 1972a and b; Volden, 1997a, 1998, 1999a and b; Gundersen, 1999) from the following materials were prepared and tested:

##### Base metals/HAZ:

- 13% Cr base metal
- 25% Cr base metal

##### Welds:

- 13% Cr pipe welded with superduplex wire
- 13% Cr pipe welded to 25%Cr pipe with superduplex wire

Fig. 1 shows the dimensions of the cylindrical Satoh test specimen.

Some specimens were also cut from real welds to simulate pure superduplex weld metal composition. Their welding is explained

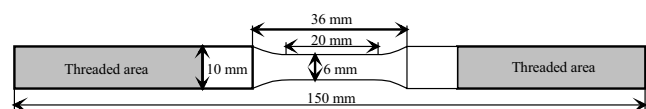


Fig. 1 Dimensions of Satoh test specimen: 20-mm-long threaded areas (MF10 × 1)

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**KEY WORDS:** Welding, weld simulation, residual stresses, start temperature for martensite transformation, supermartensitic 13% Cr stainless steel, superduplex 25% Cr steel, 25% Cr superduplex wire.