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Creep and relaxation tests report

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Summary

Numerous experiments were carried out and evaluated to get a comprehensive overview on the material properties of Alloy 800H at elevated temperature up to 850°C especially on sheet metal dimensions below 4 mm in thickness. Tensile tests were carried out to investigate the influence of temperature and strain rate to the strength and elongation properties of Alloy 800H. Relaxation and creep tests of sheet metal specimens were performed to serve as database for weld strength coefficient evaluation in the sense of a parent metal characterisation and to serve as data input for material modelling using constitutive equations.

Approval

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13/02/2015	Derek BUCKTHORPE
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16/02/2015	Steven KNOL

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Abbreviations and Symbols

CW	Crossweld
HT	High-temperature
PM	Parent metal
SM	Sheet metal
W	Weldment
WP	Welded plate

Symbols

A	Elongation (tensile test)
EL	Elongation (creep test)
Z	Reduction of area

1. Introduction

A wide database in the sense of creep and fatigue tests are currently available for Alloy 800H up to approximately 700°C. Alloy 800H was chosen to be one of the candidate materials for the intermediate heat exchanger because of its good mechanical properties, availability and its good oxidation resistance under acidic atmospheres. The material qualification in the past was usually carried out on round specimens extracted from thick sections. A gap analysis for the realisation of an HTR reactor concept showed that material data for thin section at temperatures above 700°C is still needed. Therefore the objective of this work package was to extend the material database for specimens with sheet metal dimensions of about 4 mm in thickness. Tensile tests at elevated temperatures were performed to investigate the sensitivity to strain rate variations. Furthermore creep and relaxation tests of parent metal were carried out to serve as database for weld strength factor determination and for material modelling purposes.

2. Material delivery and specimen machining

Materials are being obtained by Alfa Laval from the producers Thyssen-Krupp in the form of 4mm thick hot-rolled sheet of Alloy 800H and secondly in the form of a welded plate with a thickness of 16 mm. The contour of the sheet metal specimens was manufactured by electrical discharge machining. The thickness of the specimens was kept to its raw dimensions for parent metal specimens, which means that there was no machining of front and back side of these specimens. Round bar specimens were turned and polished afterwards to provide a good surface quality without corrugations. The drawing with final dimensions of tensile and relaxation test specimens are given in Fig. 2-1. To maintain a homogeneous stress in the gauge section, the specimen was designed to be supported at the shoulders (R15).

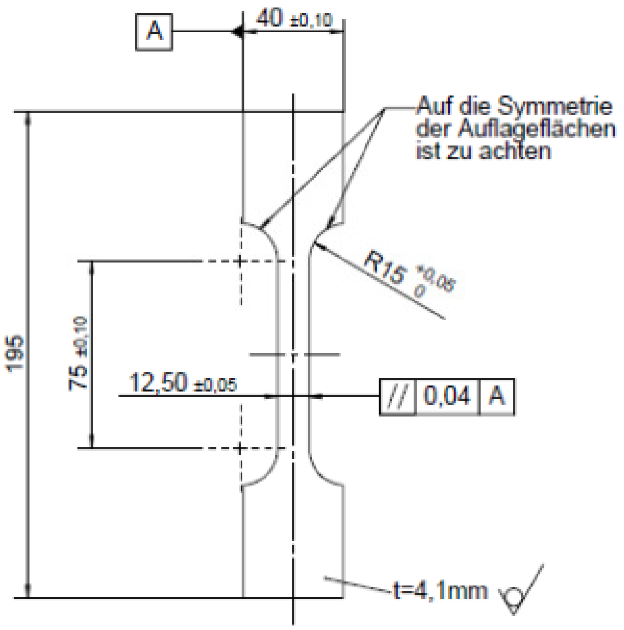


Figure 2-1: Tensile and relaxation test specimen extracted from sheet metal

The drawing of the creep specimens is given in Fig 2-2. In contrary to the tensile specimens the loading of the creep specimens was applied by a bolt. The creep tests were performed at low stresses and long periods, where no influence to the stress field in the gauge section induced by a bolt fixture can be expected. Due to the fact, that two creep specimens are tested at the same time in one line of the multi-specimen creep testing machine, the thickness of specimens (t) was adapted to fulfil the required stresses.

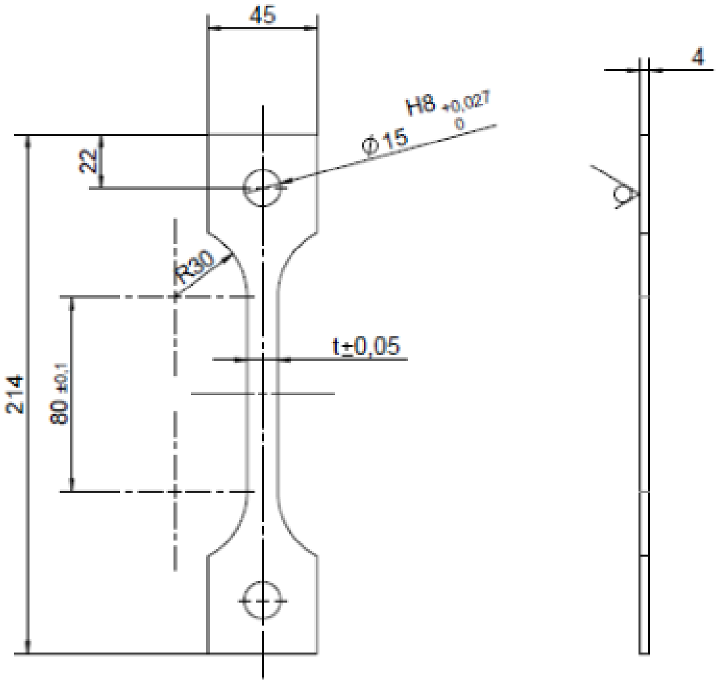


Figure 2-2: Creep test specimen extracted from sheet metal

To compare relaxation curves extracted from welds of thick sections to sheet metal weldments, it was decided to machine crossweld round bar specimens as given in the drawing of Fig. 2-3.

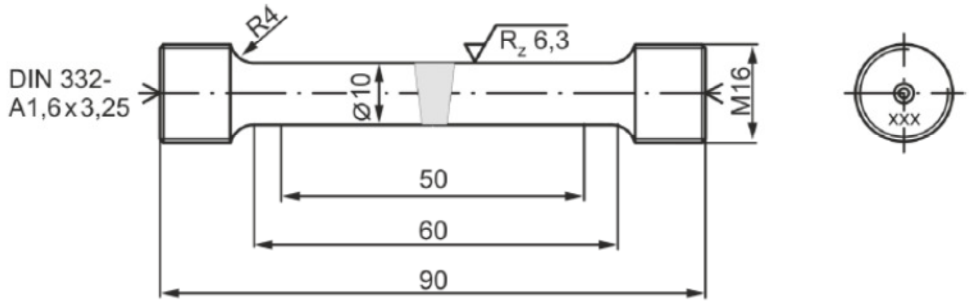


Figure 2-3: Relaxation test specimen extracted from welded plate

3. Tensile tests

The tensile and relaxation tests were performed on a Zwick® servo-electric testing machine with a resistance heated furnace. The whole assembly consisting of specimen and clamping is completely surrounded by the furnace to maintain a uniform temperature. Thermocouples were attached to the specimen and to the upper and lower clamping to monitor the temperature throughout the tests. The elongation is measured with a high temperature axial extensometer attached with ceramic rods to the specimen surface as shown in Fig. 3-1. The displacement measured by the extensometer was used to control the strain rate during the tensile tests and to maintain the applied strain in the case of relaxation testing.

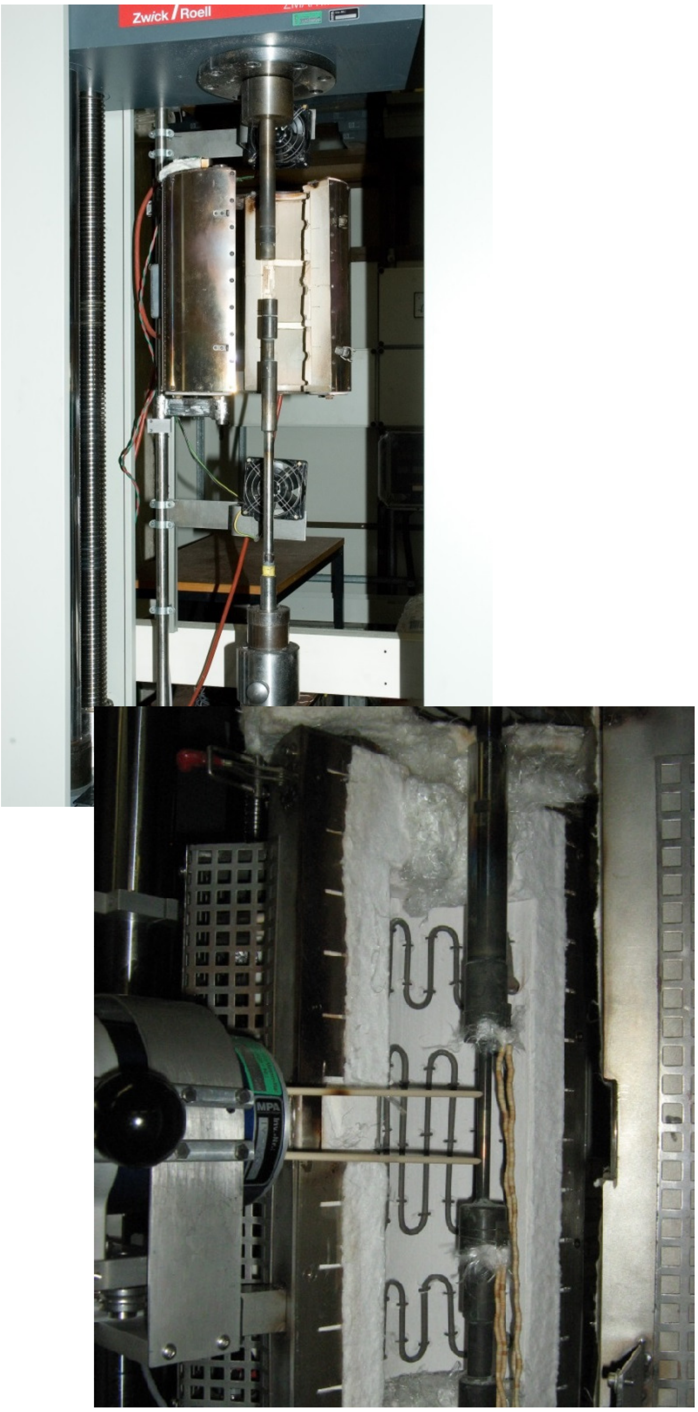


Figure 3-1: Tensile and relaxation test setup with resistance heating and HT extensometer

As already mentioned in the previous chapter, the specimens of relaxation and tensile tests were supported at the shoulder of the specimens to provide a constant stress in the gauge section. This type of clamping was particularly designed for the ARCHER project and is shown in Fig. 3-2.

Figure 3-2: Shoulder support of specimen for tensile and relaxation tests

The test conditions of the tensile tests are given in the subsequent Table 3-1. A temperature range from 650℃ to 850℃ and a strain rate ranging from 1E-5 to 5E-3 1/s was covered. Yield stress to reach 0.2%, 1% and UTS are also given in Table 3-1.

Spec.	Temp.	Strain rate	Rp0,2	Rp1	Rm	A (L=50)	Z
[-]	[℃]	[1/s]	[MPa]	[MPa]	[MPa]	[%]	[%]
T10	650	1,0E-05	162	183	311	41	43
T3	650	1,0E-04	154	176	392	54	45
T1	650	1,0E-03	159	182	410	48,5	46
T2	650	5,0E-03	148	168	402	47	51
T6	750	1,0E-05	139	159	172	39,5	44
T11	750	1,0E-04	151	174	226	52	69
T4	750	1,0E-03	162	184	264	83	60
T5	750	5,0E-03	149	172	302	57,5	62
T9	850	1,0E-05	94	95	102	25,5	21
T12	850	1,0E-04	115	119	165	74	49
T7	850	1,0E-03	140	152	155	97,5	67
T8	850	5,0E-03	147	171	190	98	72

Table 3-1: Test matrix and basic results (elongation A, reduction of area Z)

The engineering stress-strain curves for all tensile tests on thin sheet metal specimen are given in Fig. 3-3. It can be seen that the strain rate dependency rises with increasing temperatures. The material performs well showing a good ductility even for low strain rates.

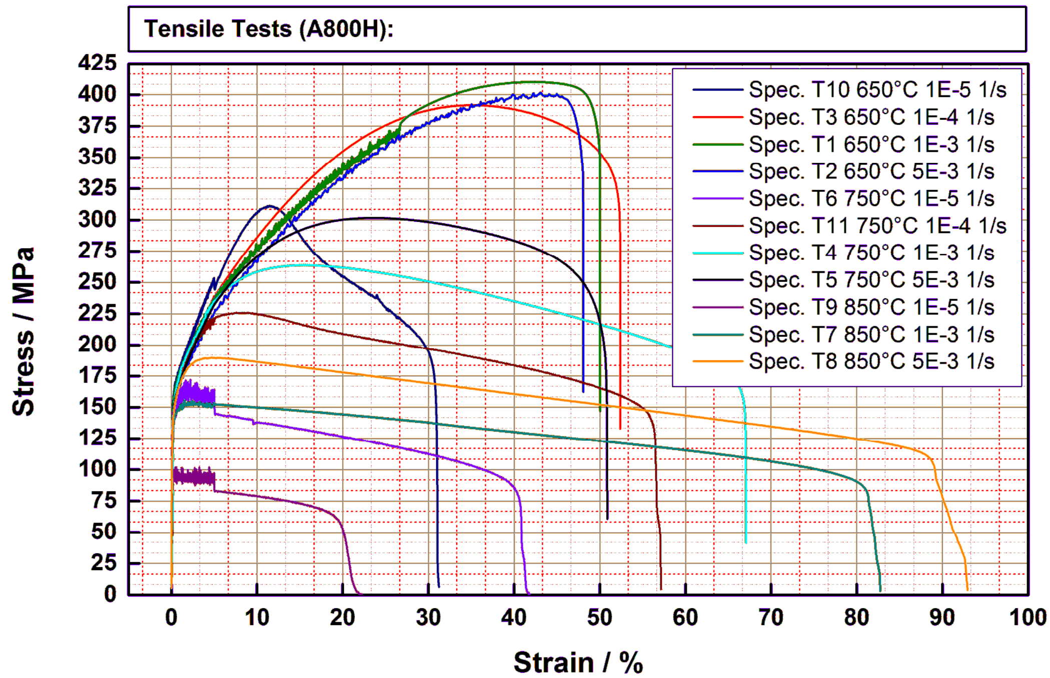


Figure 3-3: Tensile test results of sheet metal Alloy 800 H

4. Creep tests

The same creep testing conditions for parent metal specimens and laser-welded specimens were agreed after the kick-off of the ARCHER project. ALSTOM rugby lab was responsible for creep testing of laser-welded specimens, whereas the parent metal tests were launched at the MPA Stuttgart. The test conditions for parent metal and crossweld specimens are given in Table 4-1. The creep tests at MPA Stuttgart were performed in a multi-specimen creep testing machine according to ISO 204 [1] as shown in Fig. 4-1, where two specimens are tested in-line in a single furnace at the same time. A creep specimen with its fixture is shown on the right-hand side of Fig. 4-1. The target stress in multi-specimen testing machine is reached by adapting the specimen width t shown in the drawing of Fig. 2-2. The creep tests at MPA Stuttgart were performed as interrupted tests, where the specimen is taken off the machine to measure the elongation of the gauge length, marked by indentations. In contrary ALSTOM labs continuously measure the elongation at the clamping of the specimens and perform corrections to obtain the creep strain in the gauge section of the specimen.

Specimen No.		Temp (°C)	Stress (MPa)	Current or Final Duration (Hrs)	Time to % Creep Strain (hrs)							R in A (%)	Comment
					0.1	0.2	0.5	1.0	2.0	5.0	EL (%)		
1ST BATCH ALSTOM													
R1790	Weld	650	93	15714	130	490	5820	9320	13000				Ruptured
C1	PM	650	94	12946	907	5702							On Test
R1786	Weld	750	75	1048	42097	27	140	290	500	880	10,1	18,2	Ruptured
R1783	Weld	750	44	20625	2120	6360	14500						On Test
C3	PM	750	43,6	16030	8118								On Test
R1787	Weld	850	21	13215	900	3380	8700	11100	12900		3,1	5,0	Ruptured
C6	PM	850	22	16622	3331	4819	6534	7949	9526	11726			On Test
2ND BATCH ALSTOM													
R1832	Weld	650	106	8529	95	200	2200	3900	5660	8180	5,5	13,4	Ruptured
C2	PM	650	106	9946	187	1555	4063	5447	7196	8681	9,7	11,9	Ruptured
R1830	Weld	750	75	797	27546	27	100	200	370	740	14,2	25,5	Ruptured
C5	PM	750	78	1812	194	328	586	943	1163	1459	12,0	7,8	Ruptured
R1831	Weld	750	50	12210	42134	860	3340	5900	8620	12200	3,4	11,3	Ruptured
C4	PM	750	48,8	16030	5320	10561							On Test
R1835	Weld	850	24	13194	340	2760	5960	7740	9060	10800	-	-	Ruptured
C7	PM	850	24	16622	4465	5308	6671	7968	9537	11731	22,9	12,3	Ruptured
R1860	Weld	850	40	899	20	130	360	580	760		4,8	14,4	Ruptured
C8	PM	850	40	588	179	313	377	435	502	538	16,0	20,0	Ruptured

Table 4-1: Test matrix and basic results of creep tests on sheet metal specimens

The duration of the tests reached within the ARCHER project is summarized in Table 4-1. Elongation and reduction in area for ruptured specimens is also given in Table 4-1. Several tests are still running at the end of the project and exceeded the estimated runtime. This specific batch of A800 H seems to have superior creep properties compared to the ECCC mean data [2] as shown in Fig. 4-2. The tests of parent metal reached the mean curve of ECCC for 650°C and exceed the mean values in tests at 750°C and 850°C. The minimum creep ductility of parent metal specimens was reached at 650°C (EL=9,7 %). Higher temperatures (≥750°C) lead to values of 12,0 % and above.

Figure 4-1: Multi-specimen creep testing machine for two in-line arranged sheet metal specimens

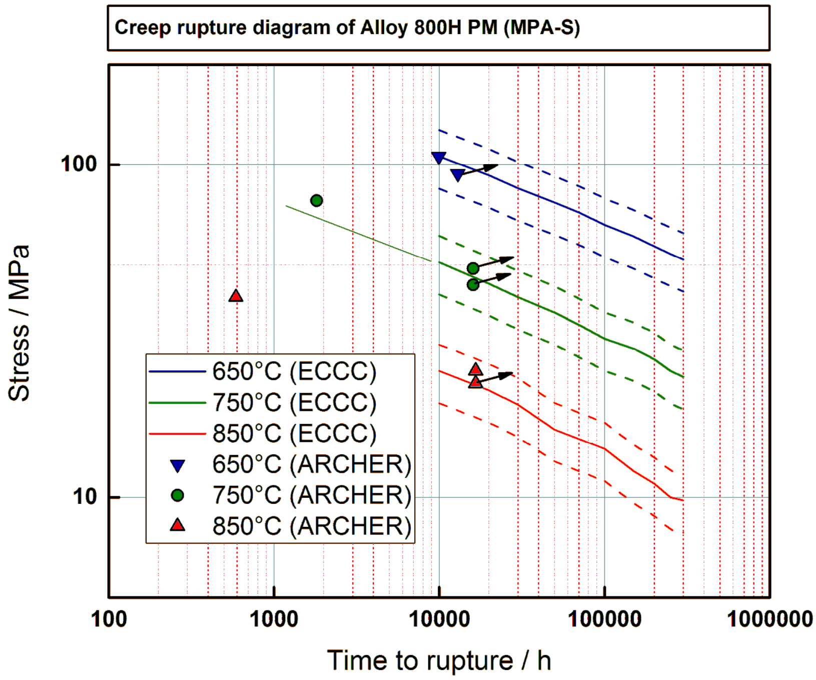


Figure 4-2: Creep rupture strength evaluation and comparison to ECCC data for A 800H

Figures 4-3 to 4-5 show the comparison of ALSTOM tests with laser-welded samples and MPA Stuttgart tests with parent metal samples for 650℃ to 850℃. For further assessments of welded specimens can be referred to the deliverable D43.55 - Test report with determination of creep weld coefficients.

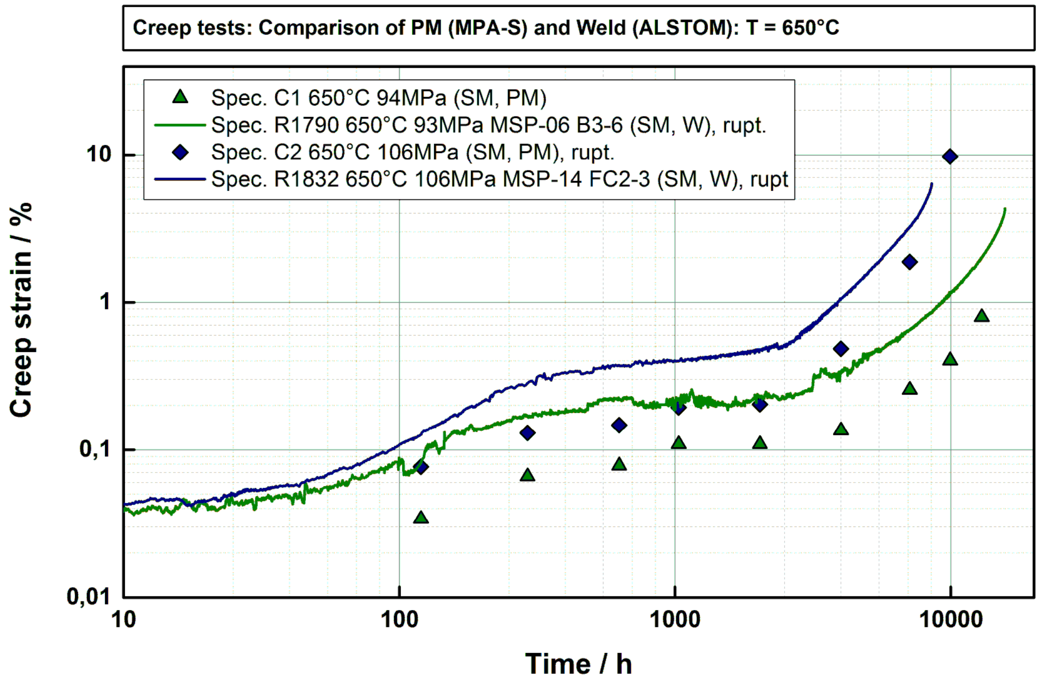


Figure 4-3: Creep strain vs. time for A800 H sheet metal specimens at 650℃ comparing parent metal and weldment

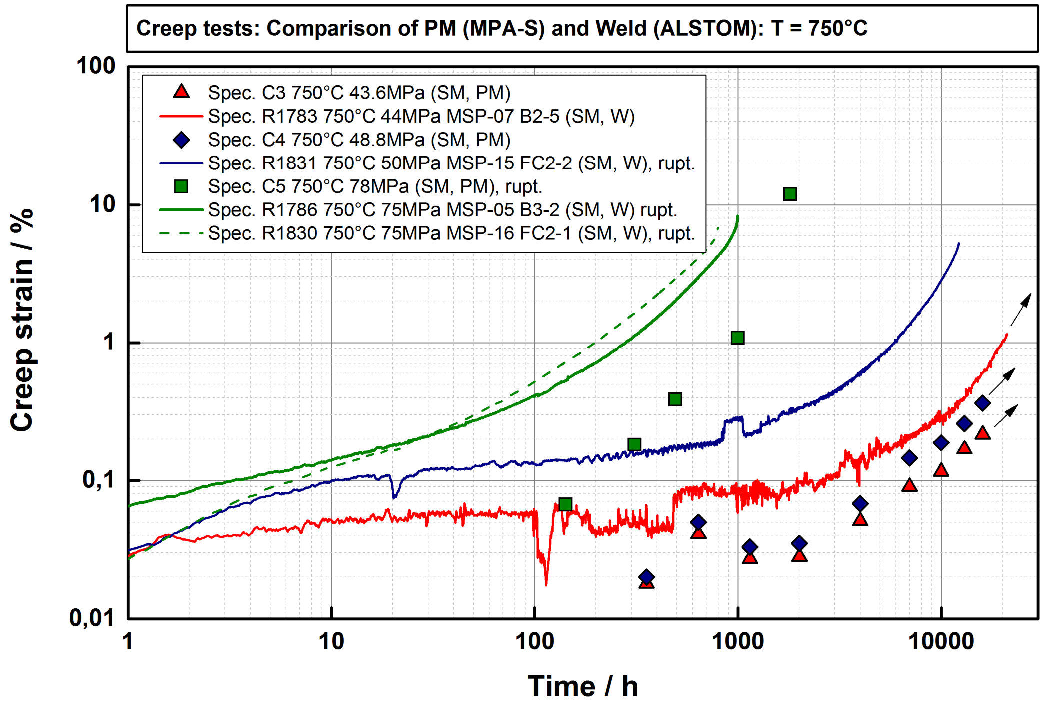


Figure 4-4: Creep strain vs. time for A800 H sheet metal specimens at 750℃ comparing parent metal and weldment

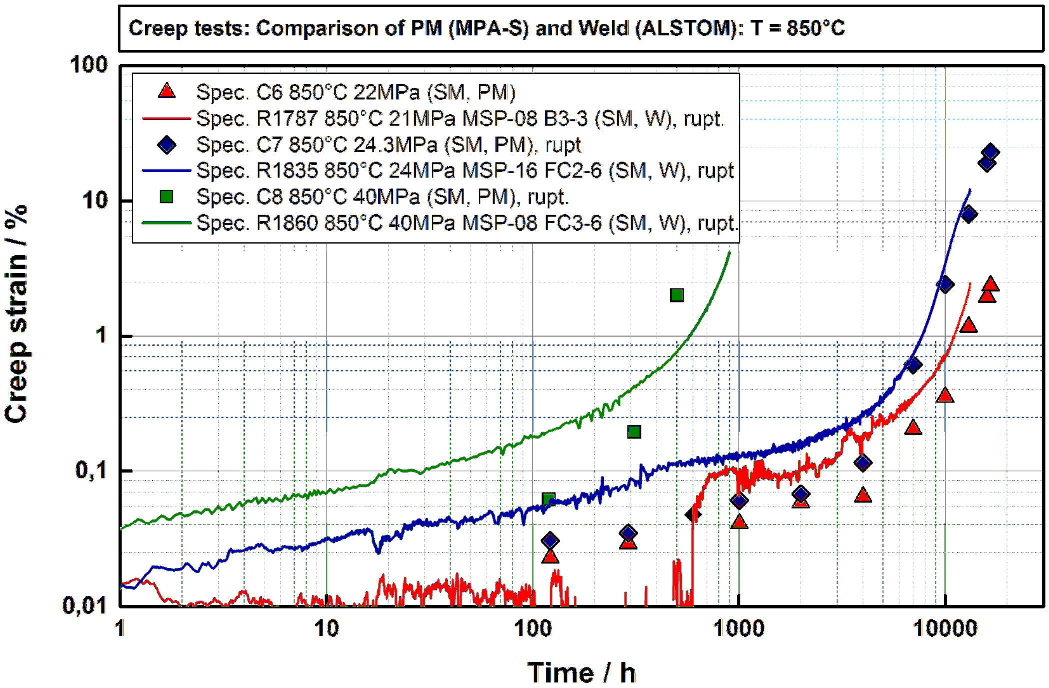


Figure 4-5: Creep strain vs. time for A800 H sheet metal specimens at 850°C comparing parent metal and weldment

Microstructure

The specimen C7 tested at 850°C for 16622 hours under creep loading was subjected to the metallographic post-examinations after the test. A macro shot of the specimen C7 is shown in Fig. 4-6.

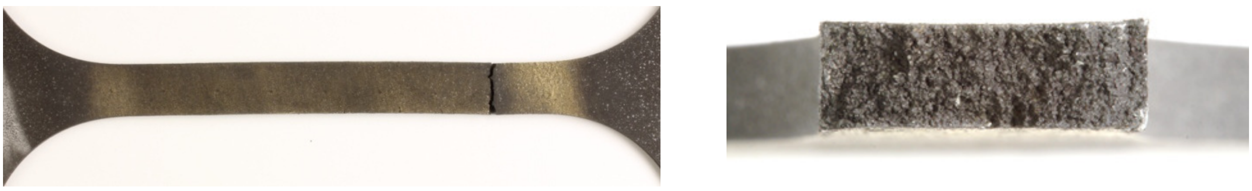
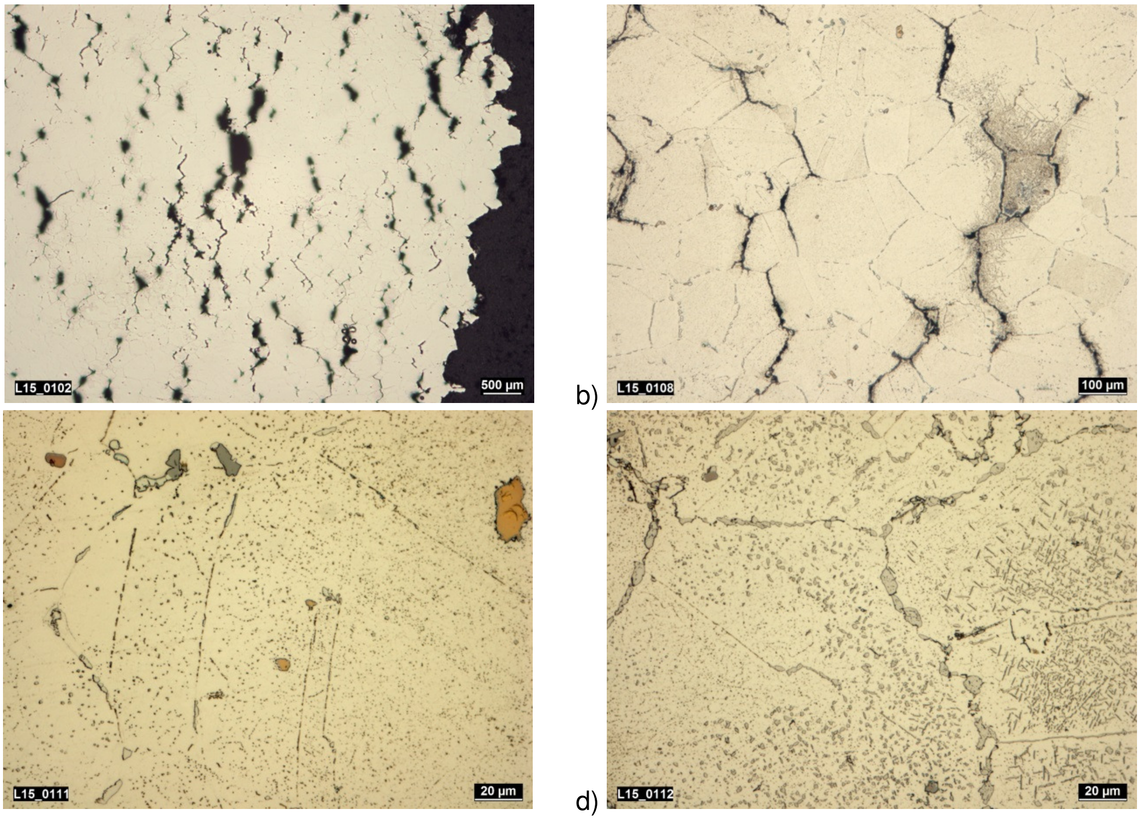


Figure 4-6: Macro shot of ruptured thin sheet specimen C7 (A800 H, 850°C, t_u = 16622 h)

For this a longitudinal cross section was prepared, and observed with an optical microscope, see Fig. 4-7 a to d. Fig. 4-7 a shows an overview of the specimen when polished, the micrographs in Fig. 4-7 b to d show states were documented in the etched conditions by using V2A- etchant.

The sample exhibits intergranular microcracks and grain boundary separations throughout the test length. The cracks are oriented perpendicular to the loading direction, see Fig. 4-7 a and b. The density of cracks is very high, even in the area 15 mm away from the fracture surface. The surfaces of the microcracks are oxidized, also in the centre of the sample. In addition, many different types of precipitates and phases can be seen in the microstructure (Fig. ??? c and d). These are both intragranular as well as intercrystalline. Within the grain small spherical particles, needle-like phase and coarse titanium carbonitrides Ti (C, N) were observed. On the twin boundaries an elongated phase is present, on the other hand, the coarse precipitates (probably carbides) are located on the high angle grain boundaries. Since the precipitates cannot be identified by using optical microscope, further investigations by SEM or TEM should be made to characterize the precipitations structure.

The high number of microcracks and grain boundary separations indicates a weakening of the grain boundaries. Whether this is caused by the oxidation or embrittling phases (G and σ-phase), which can occur in this alloy [3, 4], would need to be clarified in further analyses.



a) b) c) d)

Figure 4-7: Optical micrographs of the specimen C7 after creep rupture test at 850°C (σ=24,3 MPa, t_u = 16622°h), a) overview of un-etched specimen, b), c) and d) detail micrographs of the etched specimen with intra- and intergranular precipitates

5. Relaxation tests

The load of the intermediate heat exchanger is characterised by thermal induced stresses resulting from temperature variations during operation and thermal gradients within the heat exchanger design. These stresses are allowed to relax in time. To provide sufficient data for the stress relaxation of A 800H material for constitutive material modelling and again to compare to the laser-welded specimens of the IHX mockup to parent metal behaviour, it was decided to carry out stress relaxation tests on parent metal at 750°C and 850°C. Two initial strain levels (0.2% and 0.4% total strain) were applied.

The results of relaxation tests on sheet metal specimens are given in Fig. 5-1 and for round bar CW specimens extracted from the welded plate section in Fig. 5-2. The influence of different initial strains vanishes after several hours and the remaining stresses converge to a common value. The remaining stresses at 850°C are significantly lower compared to 750°C and even after 110 hours a significant slope for the test at 850°C remains. Comparing welded CW round bar specimens and sheet metal specimens the difference in the remaining stress after approx. 80 hours are small. The weld tends to slightly lower values at 850°C.

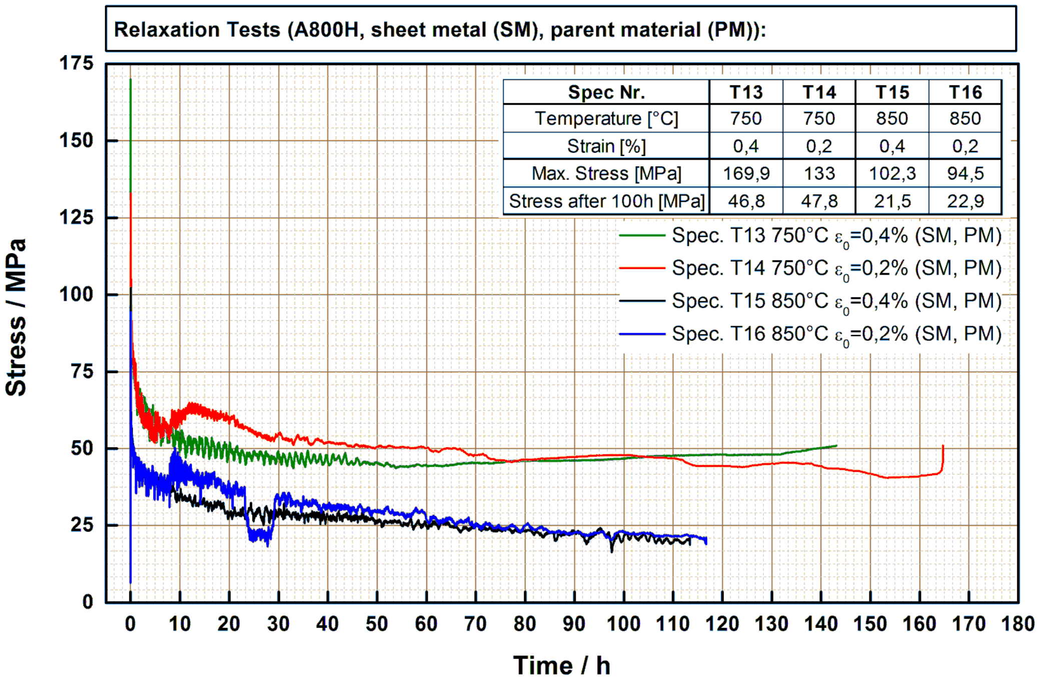


Figure 5-1: Stress vs. time for A800 H sheet metal specimen for parent metal

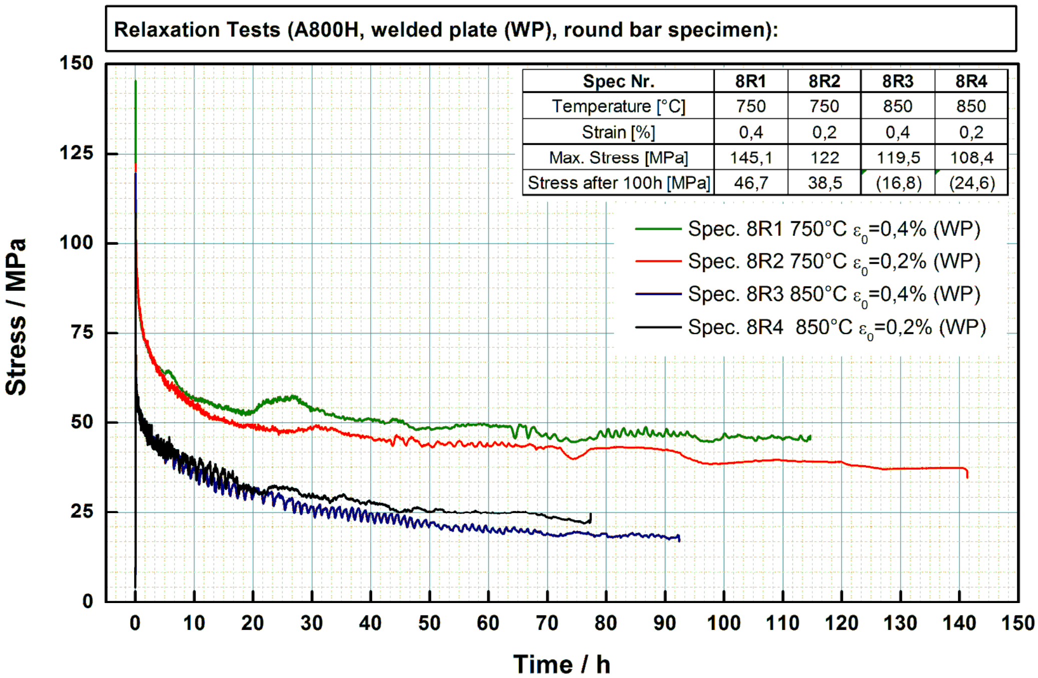


Figure 5-2: Stress vs. time for A800 H round bar specimen of welded plate

6. Conclusion

A comprehensive test program for Alloy 800H consisting of tensile, creep and relaxation tests was carried out to extend the material database for sheet metal dimensions at higher temperatures above 650℃. The tests were performed at MPA Stuttgart on parent metal, whereas similar tests with laser-welded specimens were launched in parallel at ALSTOM labs in Rugby to compare the performance of welds and parent metal. The results of these tests were provided to derive weld strength factors for laser welds and furthermore to set up material models for time-dependent material deformation which can be used in the design phase and life assessment of an intermediate heat exchanger.

7. References

[1] ISO 204:2009(en), Metallic materials — Uniaxial creep testing in tension — Method of test

[2] ECCC data sheet [Issue 2, Revision 001], Steel X8NiCrAlTi 32-21 (1.4959, Alloy 800H), 2014

[3] API PUBLICATION: Maerials, Fabrication, and Repair Considerations for Austenitic Alloys Subject to Embrittlement and Cracking in High Temperature 565 - 760℃, API-Komitees-Draft, (2012), S. 20

[4] Dehmolai, R., M. Shamaniana und A. Kermanpura: Microstructural changes and mechanical properties of Incoloy 800 after 15 years service, Materials Characterization, Vol. 60, (2009), S. 1-5