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Appendices

Appendix 1

Effect of cold working. Material solution treated at 920°C and aged at 475°C. With and without cold rolling (fig.4.3)

Aging time (h)	No reduction (8mm)		38% reduction in area (5mm)	
	hardness (HV20kg)	standard deviation	hardness (HV20kg)	standard deviation
0	167.6	4.0	248.7	5.6
0.5	171.1	5.0	274.9	4.4
1	166.3	3.3	270.3	7.2
2	173.4	4.6	275.6	4.2
4	171.1	2.9	271.5	6.3
8	172.2	4.5	277.5	5.9
16	180.6	2.8	267.7	5.5
32	171.0	3.5	271.3	8.0
64	173.7	3.5	274.5	5.6
128	174.1	3.0	280.7	6.6
260	198.0	4.6	294.9	5.7

Appendix 2

Strain aging: Chains aged at 100°C (fig. 4.6)

Aging time (h)	Hardness (HV20kg)	Standard deviation
0	251.1	5.1
0.25	254.2	6.6
0.5	251.6	4.4
1	256.1	5.5
2	254.6	4.6
4	252.6	3.6
8	249.6	3.1
16	252.1	3.4
32	252.7	3.9
64	251.4	4.8

Appendix 3

Strain aging: Sheet material solution treated at 930°C, cold rolled and aged at 100°C (fig.4.7)

Aging time (h)	Hardness (HV20kg)	Standard deviation
0.25	266.7	6.2
0.5	266.7	8.2
1	266.3	6.2
2	264.8	5.4
4	257.7	6.2
14	267.8	8.4

Appendix 4

Hardness of chain and sheet material aged at 475°C (fig.5.1)

Aging time (h)	Chain		Sheet material	
	Hardness (HV20kg)	Standard deviation	Hardness (HV20kg)	Standard deviation
0	248.5	3.9	242.3	3.8
0.5	246.2	3.1	238.7	2.5
1	249.2	4.1	242.5	3.3
2	240.6	3.6	244.5	3.8
4	245.6	3.4	240.9	3.9
8	250.0	3.4	238.3	3.2
16	250.1	3.4	242.2	3.7
32	251.2	3.6		
64	258.6	2.8	244.7	4.5
128	264.9	2.9		
260	283.4	3.9	274.8	5.7

Appendix 5

Chain aged at 450°C and 475°C (fig.5.2)

Aging time (h)	Aging at 450°C		Aging at 475°C	
	Hardness (HV20kg)	Standard deviation	Hardness (HV20kg)	Standard deviation
0	256.4	8.3	248.5	3.9
0.5	250.1	3.8	246.2	3.1
1	252.8	3.3	249.2	4.1
2	254.6	4.2	240.6	3.6
4	247.2	4.4	245.6	3.4
8	244.7	3.1	250.0	3.4
16	261.2	5.4	250.1	3.4
32	259.1	3.6	251.2	3.6
64	267.9	6.0	258.6	2.8
128	269.3	3.9	264.9	2.9
260	280.1	4.2	283.4	3.9

Appendix 6

Sheet material aged at 400°C, 475°C and 500°C (fig.5.3)

Aging time (h)	400°C		475°C		500°C	
	Hardness (HV20kg)	Standard deviation	Hardness (HV20kg)	Standard deviation	Hardness (HV20kg)	Standard deviation
0.5	246.2	5.1	242.3	3.8	234.9	3.8
1	246.7	3.8	238.7	2.5	235.8	4.1
2	242.4	5.9	242.5	3.3	234.3	5.2
4	242.4	4.5	244.5	3.8	234.7	3.7
8	238.9	5.7	240.9	3.9	235.5	4.8
16	240.7	4.1	238.3	3.2	233.5	4.9
32	240.8	3.4	242.2	3.7	235.5	3.8
48	246.1	4.1				
64			244.7	4.5	237.8	2.9
128					238.4	3.7
260			274.8	5.7	236.7	3.9

Appendix 7

Equilibrium volume fractions α" (fig.5.4)

Temperature (°C)	Volume fraction α"
427	0.06
435	0.055
450	0.05
465	0.04
475	0.02
485	0.008

Appendix 8

Hardness after solution treatments at different temperatures. 15 minutes at temperature, water quench, no reduction (fig.6.1)

Solution temperature (°C)	Hardness (HV20kg)	Standard deviation	% Martensite*
800	161.7	2.0	-
825	160.9	1.6	-
850	162.5	2.3	-
875	153.9	2.9	-
900	165.7	2.3	-
925	177.0	4.1	14.0
950	209.1	4.7	32.0
975	219.8	6.0	35.5
1000	221.0	5.5	34.7
1025	211.4	10.0	30.2
1050	204.9	9.6	25.5
1075	190.0	5.1	10.0
1100	196.6	6.4	4.5
1125	201.2	5.3	0.5
1150	214.4	9.1	-
1175	236.4	10.6	-
1200	252.0	8.8	-

* % martensite determined by etching in Ralph's etchant and using a point count method (200 points per specimen)

Appendix 9

Solution treatment at 930°C (45 min) and 990°C (45 min), cold rolling and aging at 475°C (fig.6.4)

Aging time (h)	930°C		990°C	
	Hardness (HV20kg)	Standard deviation	Hardness (HV20kg)	Standard deviation
0	260.5	6.2	288.1	8.1
0.5	287.2	9.4	306.9	7.9
1	293.5	8.8	296.6	8.6
2	297.2	9.2	311.0	8.5
4	289.7	6.1	309.2	7.4
8	296.3	8.2	302.1	7.8
16	286.5	7.5	301.7	7.0
32	290.9	7.2	302.7	6.8
64			304.9	6.8
128	298.1	5.2	311.3	6.0
260	306.6	5.1	312.9	4.7
520	311.8	4.6	320.7	4.5

Appendix 10

Solution treatment at 880°C and 930°C, and aging at 475°C (fig.6.5)

Aging time (h)	880°C		930°C	
	Hardness (HV20kg)	Standard deviation	Hardness (HV20kg)	Standard deviation
0	247.1	6.3	257.9	5.5
0.03*	267.1	8.2	304.1	8.8
0.07*	272.0	5.7	309.8	7.2
0.13*	274.2	7.7	306.6	8.6
0.25*	268.5	6.4	303.2	11.1
0.5*	265.1	5.2	304.9	8.9
0.5	262.8	5.5	306.9	12.9
1	260.1	4.5	306.5	12.6
2	261.6	6.2	289.7	10.5
4	259.8	4.4	293.0	8.0
8	265.5	4.8	296.6	10.5
16	258.8	3.2	287.2	6.8
32	259.3	3.9	284.7	8.2
64	266.3	6.8	289.8	7.3
128	276.3	5.3	292.4	6.5
260	289.7	5.8	302.6	5.3
544	302.4	3.4	310.4	5.3
1040	308.9	5.6	319.8	6.7
2072	318.8	4.2	326.7	5.8

* Aged in weld cycle simulator

Appendix 11

Solution treatment at 880°C and 930°C, and aging at 450°C (fig.6.8)

Aging time (h)	880°C		930°C	
	Hardness (HV20kg)	Standard deviation	Hardness (HV20kg)	Standard deviation
0	241.8	3.0	281.3	11.1
0.03*	268.5	5.1	313.3	15.1
0.07*	268.9	6.9	298.8	8.2
0.13*	266.4	4.9	320.6	9.3
0.25*	266.9	5.1	305.7	14.3
0.5*	269.5	5.2	319.7	10.2
0.5	274.0	4.6	325.4	11.6
1	273.8	6.8	321.7	7.7
2	267.3	4.6	326.0	16.2
4	273.5	3.8	321.3	5.3
8	268.6	5.3	322.3	12.2
16	264.8	5.9	323.9	8.8
32	266.5	4.9	319.1	
64	270.9	5.2	323.4	8.3
128	273.7	6.3	317.2	8.8
260	282.4	5.0	320.7	5.8
520	301.4	7.0	322.1	9.9

* Aged in weld cycle simulator

Appendix 12

Distribution of hyperfine field (T) with aging time (fig. 6.11)

Aging time at 475°C	solution treated at 880°C	solution treated at 930°C
0	26.92	26.73
8 minutes	27.08	26.98
32 hours	27.14	27.20
260 hours	27.65	27.57
2072 hours	27.99	28.13

Appendix 13

Impact strength and % lateral expansion (fig.7.1 and 7.2)

	Aging time at 475°C	Impact strength (J/mm^2)	% Lateral expansion
Solution at 880°C	0	0.84	33.3
	0	-	-
	0	0.80	30.1
	0	0.58	21.3
	8 minutes	0.05	2.4
	8 minutes	0.05	1.8
	8 minutes	0.10	2.0
	8 minutes	0.06	1.8
	32 hours	0.06	1.2
	32 hours	0.06	1.0
	32 hours	0.05	0.4
	32 hours	0.31	11.2
Solution at 930°C	0	0.14	8.8
	0	0.23	11.2
	0	0.06	1.8
	0	0.07	1.8
	8 minutes	0.04	2.8
	8 minutes	0.04	3.4
	8 minutes	0.03	0.2
	8 minutes	0.04	2.8
	32 hours	0.04	2.6
	32 hours	0.05	2.8
	32 hours	0.03	1.2
	32 hours	0.04	2.0

Appendix 14

K_{1c} values and critical crack length (fig.7.3)

	Aging time at 475°C	K_{1c}	Critical crack length (mm)
Solution at 880°C	0	315.0079	80.901
	0	305.4638	760.73
	0	240.0011	46.961
	8 minutes	38.1830	0.804
	8 minutes	38.1830	0.804
	8 minutes	64.2159	2.274
	8 minutes	43.7780	1.057
	32 hours	43.7780	1.115
	32 hours	43.7780	1.115
	32 hours	39.3228	0.899
	32 hours	150.9315	13.248
Solution at 930°C	0	83.3124	4.643
	0	119.3457	9.528
	0	43.7780	1.282
	0	50.7148	1.720
	8 minutes	34.3961	0.509
	8 minutes	33.2031	0.475
	8 minutes	26.0305	0.292
	8 minutes	32.2989	0.449
	32 hours	34.3961	0.534
	32 hours	40.7324	0.749
	32 hours	26.0305	0.306
	32 hours	32.2989	0.471

Appendix 15

Uniform plastic strain (fig.7.10)

Aging time (h)	880°C solution treatment	930°C solution treatment
0	0.0110	0.0094
0	0.0124	0.0093
0	0.0110	0.0110
0	0.0180	0.0123
8 minutes	0.0383	0.0387
8 minutes	0.0260	0.0428
8 minutes	0.0334	0.0466
8 minutes	0.0311	0.0499
32 hours	0.0466	0.0490
32 hours	0.0394	0.0463
32 hours	0.0325	0.0652
32 hours	0.0408	0.0641
277 hours	0.0384	0.0485
277 hours	0.0473	0.0480
277 hours	0.0344	0.0506
277 hours	0.0447	0.0509

Appendix 16

Strain -to-failure in width and thickness directions (880°C and 930°C)

(fig. 7.13 and 7.14)

	Aging time at 475°C	ε_w	ε_t
Solution at 880°C	no deformation, no aging	-0.327	-1.052
	no deformation, no aging	-0.349	-1.104
	no deformation, no aging	-0.330	-1.001
	0	-0.293	-0.839
	0	-0.316	-0.916
	0	-0.317	-1.033
	8 minutes	-0.249	-0.718
	8 minutes	-0.223	-0.693
	8 minutes	-0.202	-0.639
	8 minutes	-0.239	-0.680
	32 hours	-0.161	-0.618
	32 hours	-0.256	-0.756
	32 hours	-0.235	-0.791
	32 hours	-0.255	-0.753
	277 hours	-0.207	-0.539
	277 hours	-0.170	-0.553
	277 hours	-0.192	-0.518
	277 hours	-0.159	-0.620

Appendix 16 (continued)

	Aging time at 475°C	ε_w	ε_t
	no deformation, no aging	-0.185	-0.594
	no deformation, no aging	-0.210	-0.616
	no deformation, no aging	-0.215	-0.628
	0	-0.194	-0.574
	0	-0.163	-0.618
	0	-0.202	-0.680
	0	-0.213	-0.718
Solution at 930°C	8 minutes	-0.192	-0.511
	8 minutes	-0.186	-0.456
	8 minutes	-0.132	-0.299
	8 minutes	-0.103	-0.203
	32 hours	-0.213	-0.554
	32 hours	-0.217	-0.511
	32 hours	-0.178	-0.375
	32 hours	-0.192	-0.399
	277 hours	-0.182	-0.488
	277 hours	-0.207	-0.414
	277 hours	-0.153	-0.369
	277 hours	-0.122	-0.325

Appendix 17

R-ratio of strains ($\varepsilon_w/\varepsilon_t$) (fig. 7.15)

Aging time (h)	880°C solution treatment	930°C solution treatment
no derormation, no aging	0.311	0.312
no derormation, no aging	0.316	0.341
no derormation, no aging	0.330	0.342
0	0.349	0.337
0	-	0.264
0	0.344	0.297
0	0.307	0.296
8 minutes	0.347	0.375
8 minutes	0.322	0.408
8 minutes	0.316	0.441
8 minutes	0.352	0.509
32 hours	0.261	0.384
32 hours	0.338	0.424
32 hours	0.297	0.475
32 hours	0.339	0.481
277 hours	0.384	0.373
277 hours	0.307	0.500
277 hours	0.372	0.414
277 hours	0.256	0.375

Appendix 18

Difference between true strain in the neck and true strain at necking (fig. 7.16)

Aging time (h)	880°C solution treatment	930°C solution treatment
no deformation no aging	-1.052	-0.678
no deformation no aging	-1.104	-0.704
no deformation no aging	-1.001	-0.708
0	-0.839	-0.584
0	-	-0.628
0	-0.926	-0.691
0	-1.043	-0.730
8 minutes	-0.749	-0.542
8 minutes	-0.715	-0.489
8 minutes	-0.667	-0.333
8 minutes	-0.705	-0.239
32 hours	-0.657	-0.592
32 hours	-0.788	-0.546
32 hours	-0.819	-0.442
32 hours	-0.786	-0.445
277 hours	-0.569	-0.526
277 hours	-0.592	-0.448
277 hours	-0.546	-0.408
277 hours	-0.659	-0.365

Appendix 19

Tensile strength and 0.2% yield stress of 880°C and 930°C specimens
(figure 7.19)

	Aging time (h)	Tensile strength (MPa)	0.2% Yield stress (MPa)
Solution at 880°C	0	685	597
	0	679	611
	0	691	652
	0	672	618
	0.13	783	745
	0.13	802	766
	0.13	806	763
	0.13	811	773
	32	810	740
	32	811	741
	32	808	740
	32	800	733
	277	805	745
	277	893	824
	277	893	826
	277	912	846

Appendix 19 (continued)

	Aging time (h)	Tensile strength (MPa)	0.2% Yield stress (MPa)
Solution at 930°C	0	741	705
	0	749	711
	0	734	680
	0	731	655
	0.13	869	802
	0.13	871	826
	0.13	990	816
	0.13	968	890
	32	871	793
	32	887	811
	32	979	883
	32	979	874
	277	933	861
	277	908	838
	277	994	900
	277	1003	903