MECHANICAL PROPERTIES OF WARM COMPACTED ASTALOY CrM

Caroline Lindberg
Björn Johansson
Barbara Maroli

Höganäs AB
S-263 83 Höganäs, Sweden

ABSTRACT

The Astaloy CrM powder is a high strength prealloyed powder containing 3 % Cr and 0.5 % Mo. It reaches a very high strength in the range of 120 ksi (850 MPa) after conventional compaction at room temperature and sintering in belt furnaces at 2050°F (1120 °C). The strength can be improved further by applying high temperature sintering. Another way to improve the strength further is to utilise warm compaction.

The compressibility of this high- and prealloyed powder is naturally lower compared to a plain iron powder. Due to optimisation of the composition and the production process it achieves a high compressibility of about 7.0 g/cm³ at a compacting pressure of 43 tsi (600 MPa) for the plain powder. The density is increased 0.15 g/cm³ by using warm compaction with the same compacting pressure. This density increase will of course improve the mechanical properties.

INTRODUCTION

The growth of the PM industry today is mainly related to new components not previously produced by the PM-technique. In order to be competitive with other techniques there are three main objectives to be fulfilled:

- High strength
- Tight tolerances
- Low cost

In this paper we will look on one material and a processing route that can help to fulfil these requirements namely Astaloy CrM and warm compaction. Astaloy CrM is a water atomized powder prealloyed with 3 % Cr and 0.5 % Mo. This material was introduced in the end of –98. Today there is already three components in production and a lot of development projects are ongoing. The warm compaction and related powder mixes were introduced in –94 and today there are some 250 parts in production. This technique is used both to replace parts earlier produced by 2P2S and infiltration as well as for new components earlier not produced by PM.

EXPERIMENTS

The Astaloy CrM powder was mixed with different amounts of graphite, UF4 from Kropfmühl, in the range of 0,3-0,6 %. Mixes for warm compaction, DENSMIX™, were prepared using 0.6 % Lube. The conventional premixes used as reference include 0.8 % Zn-st. These are typical mixes for warm compaction and conventional compaction. When the geometry is very complicated, higher amounts of lubricant can be needed. Tensile strength specimens according to standard ISO 3927-1985 were compacted at 36, 43 and 50 tsi (500, 600 and 700 MPa) by conventional compaction at room temperature (RT) as well as by warm compaction. The warm compaction was done using a slot heater in order to heat the powder to 266ºF (130°C). The die was heated with cartridge heaters to a temperature of 284°F (140°C), see Fig 1.

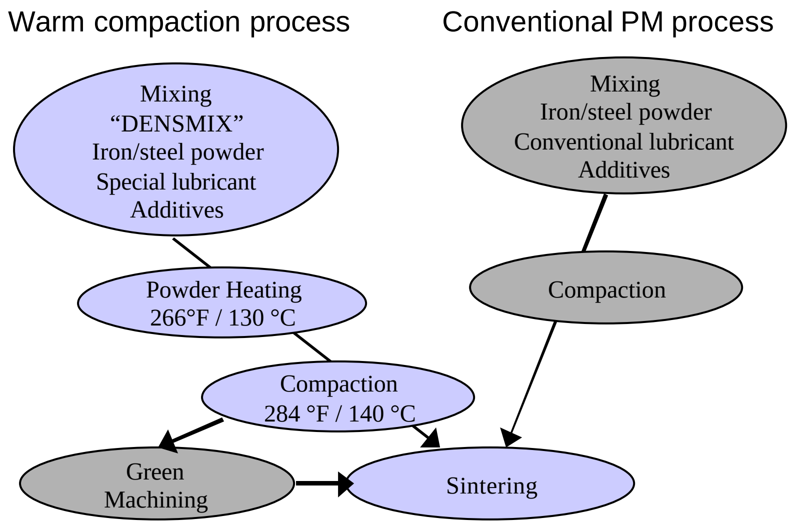

Figure 1. Schematic flow diagram for Warm compaction and conventional PM process

Sintering was done in two different furnaces. The first sintering was done at 2050°F (1120°C) in a laboratory sintering furnace for 30 minutes at temperature. The atmosphere was 75/25 N_2/H_2 with addition of methane. Samples with 0.3 and 0.4 % graphite were sintered with a methane addition of approximately 0.6 % methane and samples with 0.5 and 0.6 % graphite were sintered with 1.1 % added. The methane addition does also have a positive effect on the partial pressure of oxygen that is decreased. The cooling rate of this furnace is about 0.8 °C/s.

The second sintering was done at high temperature, 2280°F (1250°C), in a production furnace of walking beam type. The sintering was done for 70 minutes at temperature in a 90/10 N_2/H_2 atmosphere. The sintering trial was done during production of PM parts. The partial pressure of oxygen was not measured but it is known to be well below $5*10^{-18}$ which is the critical level for oxidation of plain Astaloy CrM without graphite addition.

RESULTS AND DISCUSSION

Green density

The results show that we have a good compressibility, especially when considering the high amounts of alloying elements that are prealloyed. A green density of 7.00 g/cm^3 is reached for Astaloy CrM + 0.4 % graphite at a compacting pressure of 50 tsi (700 MPa) for the conventional compaction at RT. This is increased with 0.19 g/cm^3 up to 7.21 g/cm^3 when warm compaction is applied. For varying graphite additions and compacting pressures the increase is in the range of 0.17-0.20 g/cm^3. This improvement is in the same range as earlier seen for materials like D. AE + graphite [1]. Complete tables with data are found in the Appendix.

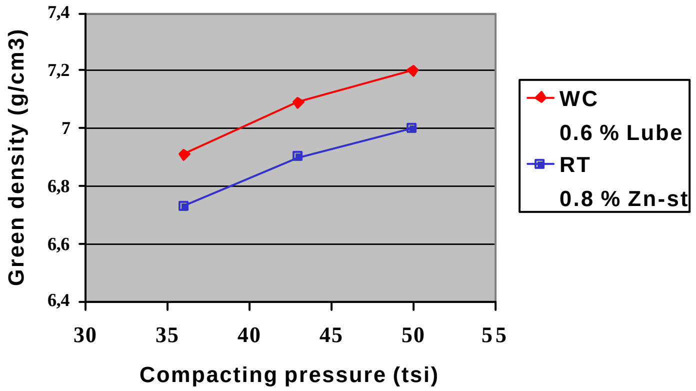

Figure 2. Green density of Astaloy CrM + 0.4 % graphite compacted at different compacting pressures by warm compaction and conventional compaction at room temperature.

Sintering in belt furnace, 2050°F (1120°C)

The carbon and oxygen contents were evaluated after sintering. There has been a small decarburization in the range of 0.02-0.06 % for materials sintered at 2050°F (1120°C). The oxygen content varies from 0.09 to 0.11 %. The lower values are seen for materials with the higher graphite additions and with the lower densities. The oxygen content is slightly higher for the warm compacted materials. This is mainly due to the higher density levels achieved. The variations in O-contents are however small.

The tested materials show a small shrinkage when measuring the dimensional change from green to sintered. This shrinkage is smaller for the warm compacted material compared to material compacted at RT. The sintered densities are in the same range as the green densities.

Hardness increased with density as well as with carbon content, as expected. The increase in hardness caused by increasing C-contents is however much larger compared to most PM materials. For RT compacted materials the hardness is more than doubled when the carbon content is increased from 0.26

to 0.56 %. It starts at 221 HV10 and is increased up to 476 HV10 at 50 tsi (700 MPa) in compacting pressure. The latter is a very high hardness especially for being in the sintered condition.

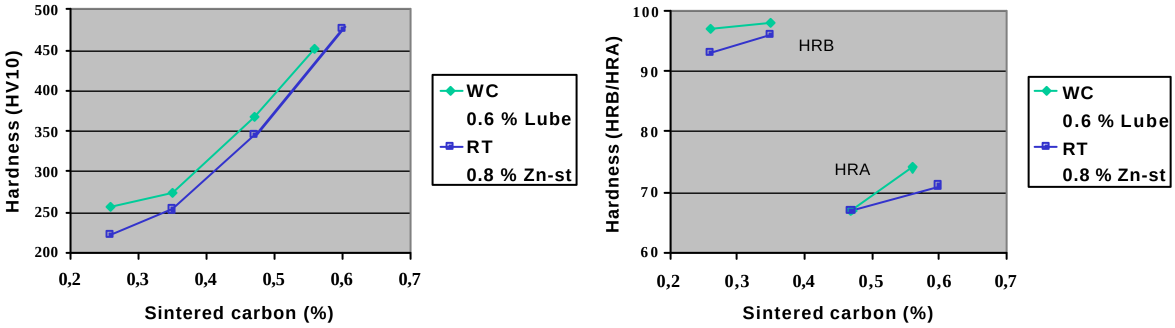

Figure 3. Hardness measured by Vickers with 10 kg load as well as Rockwell B and A respectively for different sintered carbon contents.

The yield and tensile strength follows the same pattern as the hardness. The tensile strength increases for increasing carbon contents up to 0.56 %. A tensile strength of 133 ksi (931 MPa) was reached for the warm compacted material at 50 tsi (700 MPa). The corresponding yield strength was 114 ksi (796 MPa). This is even higher than earlier evaluated for D. AE tested under the same conditions [2].

Sintering in walking beam furnace, 2280°F (1250°C)

The sintered oxygen contents have decreased considerably when the sintering temperature is increased. The oxygen contents vary from 0.020 % down to 0.005 %. It should be compared to oxygen contents of 0.09-0.11% for materials sintered at 2050°F (1120°C). For this high temperature sintering it was not possible to add any hydrocarbon. This has caused some decarburization. The carbon has both reacted with the chromium oxides, which have been reduced, as well as with the sintering atmosphere. This has caused a larger decarburization compared to materials sintered at lower temperature. The decarburization varies in the range of 0.12-0.19 %. The largest decarburization is seen for materials with the largest graphite addition and with the lowest density. It is important to note that the decarburization is even through the cross section. This type of decarburization can be accepted. A surface decarburization would cause decreased mechanical properties, especially hardness.

Table I. Chemical analysis of Astaloy CrM with different graphite additions sintered at 2280°F.

No	P (tsi)	% gr added	% C sintered	% C loss	% O sintered
1	43 WC	0,3	0,18	0,12	0,009
2	36 WC	0,4	0,26	0,14	0,009
2	43 WC	0,4	0,26	0,14	0,009
2	50 WC	0,4	0,25	0,15	0,017
3	43 WC	0,5	0,36	0,14	0,008
4	43 WC	0,6	0,44	0,16	0,011
5	43 RT	0,3	0,16	0,14	0,009
6	36 RT	0,4	0,26	0,14	0,009
6	43 RT	0,4	0,26	0,14	0,008
6	50 RT	0,4	0,26	0,14	0,008
7	43 RT	0,5	0,34	0,14	0,008
8	43 RT	0,6	0,41	0,19	0,010

The shrinkage from green to sintered size has increased as an effect of the increased sintering time and especially due to the higher temperature. A slightly smaller shrinkage is seen for materials that are warm compacted. The larger shrinkage has had a positive effect on the sintered density that is increased. The sintered densities are in general 0.08 g/cm^3 higher compared to the green densities. Both warm compaction as well as the higher sintering temperature has a positive effect on the porosity. In figure 4 it can be seen that the total porosity, pore size as well as pore shape is improved.

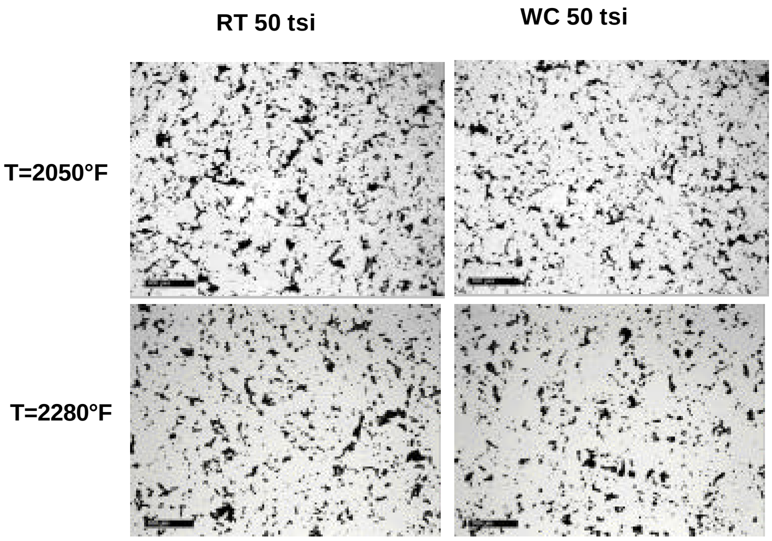

Figure 4. Pore structure of Astaloy CrM + 0.4 % graphite compacted at 50 tsi by conventional and warm compaction. Material has been sintered at 2050°F as well as 2280°F.

The hardness values are lower compared to materials sintered at 2050°F (1120°C) both when comparing materials with the same graphite addition as well as sintered carbon content. This is due to a higher cooling rate in the belt furnace used for the low temperature sintering.

Yield strength and tensile strength on the other hand are much higher for the high temperature sintered material. When comparing the tensile strength between conventional compacted and warm compacted material there is an increase of 15-25 ksi (100-175 MPa). The tensile strength of warm compacted Astaloy CrM + 0.4 % graphite, with a sintered carbon content of 0.35 %, starts at 121.0 ksi (845 MPa) at a compacting pressure of 36 tsi (500 MPa). It increases up to 136.3 ksi (952 MPa) when the compacting pressure is increased to 50 tsi (700 MPa). This is due to the corresponding density increase of 0.28 g/cm^3.

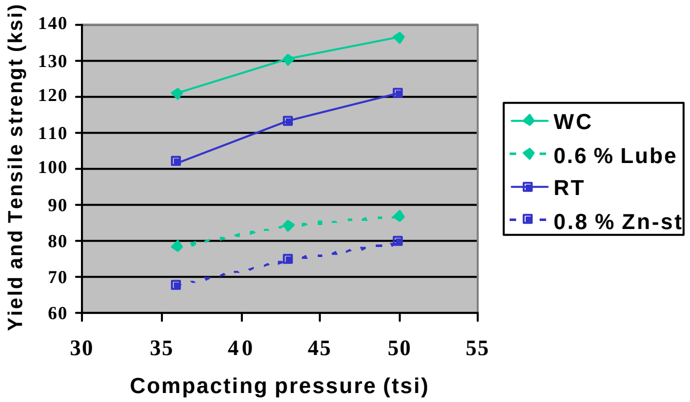

Figure 5. Yield strength and tensile strength of Astaloy CrM + 0.25 %carbon warm compacted and conventional compacted at room temperature sintered at 2280°F (1250°C).

The strength increases with increasing carbon contents. The highest properties were reached for Astaloy CrM with an addition of 0.6 % graphite (0.45 % C) warm compacted at 50 tsi (700 MPa). This material reached a tensile strength of 186.0 ksi (1299 MPa) and a yield strength of 118.0 ksi (824 MPa).

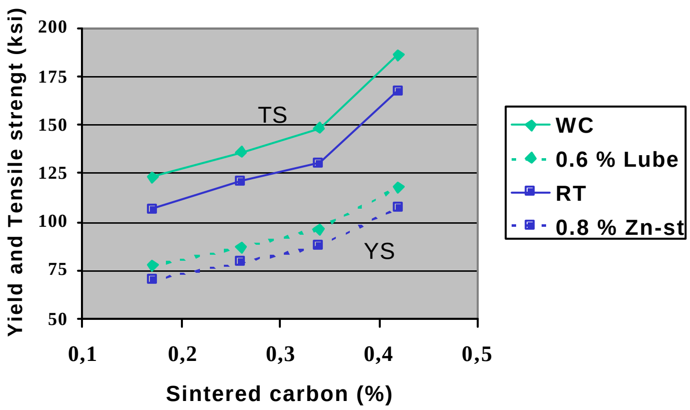

Figure 5. Yield and tensile strength of Astaloy CrM with different carbon contents conventionally and warm compacted at 50 tsi. Sintering was done at 2280°F for 70 minutes.

The increase in yield and tensile strength with increasing carbon content is an effect of the change in microstructure. It consists of bainite and a very small amount of ferrite in the sample with 0.3 % graphite, 0.17 % sintered carbon content. In Astaloy CrM with 0.26 % C the bainite has become slightly finer and a very small amount of martensite can be found, less than 1 %. The bainite becomes even finer as the carbon content is increased to 0.33 %. The amount of martensite has increased, but is still at a very low amount. In the sample with 0.43 % C a larger change can be seen. Here we have a matrix of low temperature bainite that is very fine with larger amounts of martensite in-between. This gradual change in microstructure has caused the improvement of both hardness and strength.

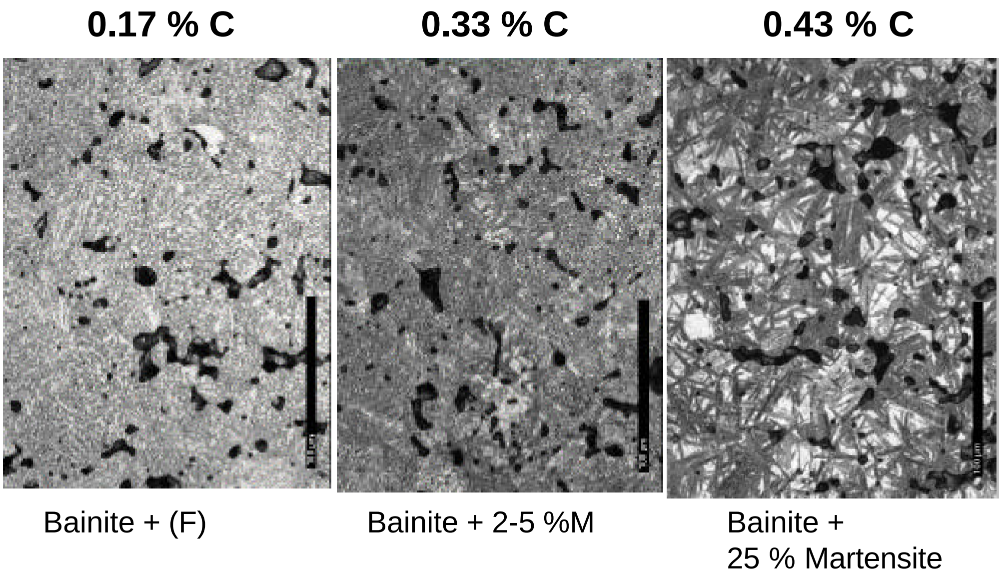

Figure 6. Microstructure of Astaloy CrM with different amounts of carbon sintered at high temperature, 2280°F.

The high temperature sintering does also have a positive effect on the elongation of the materials. A major increase can be seen both for materials compacted at RT as well as for warm compacted materials. The latter has elongation data in the range of 1.5 to 5.0 % with the highest values for higher compacting pressures and lower graphite additions.

The carbon content and processing route to be selected for different applications strongly depends on the required properties. A good combination of strength and ductility is achieved at carbon contents of 0.3-0.35 %. If hardness and static strength is the most important and ductility is not so critical, higher carbon contents can be used. The static properties show an increase for increasing carbon contents all the way up to 0.6 % under the used processing conditions.

CONCLUSION

Astaloy CrM has shown to be a base powder with very high compressibility when considering the high amount of alloying elements that are prealloyed. With an addition of 0.4 % graphite and at a compacting pressure of 50 tsi (700 MPa) a green density of 7.00 g/cm^3 is reached. It is increased up to 7.20 g/cm^3 when warm compaction is applied for the same mix and at the same compacting pressure.

The material has a very good hardenability and a hardness > 70 HRA (450 HV10) is achieved for material sintered in a conventional furnace at 2050°F (1120°C).

Warm compaction has a very positive effect on mechanical properties especially when combined with high temperature sintering. The tensile strength is increased 15-25 ksi (100-175 MPa) when comparing warm compacted material sintered at 2050°F (1120°C) and 2280°F (1250°C). Astaloy CrM + 0.6 % graphite warm compacted at 50 tsi (700 MPa) reaches a very high tensile strength of 186 ksi (1299 MPa) in the sintered condition. This is a strength level that normally takes heat treatment to reach. The benefit with this material and process selection is that it is achieved in combination with an elongation at 1.9 % and to a lower cost.

The microstructure depends strongly on the amount of sintered carbon. For carbon contents of 0.15 % the microstructure is bainitic possible with some very small amounts of ferrite. Martensite starts to form at 0.25% and at 0.4 % it has reached roughly 25 %. Another important factor is the cooling rate. That has been studied in a separate paper [3].

REFERENCES

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2. J. Tengzelius, "Höhere dichten durch warmpressen, Symposium in Hagen, Nov. 1995

3. U. Engström, "Evaluation of sinter hardening of different PM materials

Astaloy CrM RT/WC

WC: 0.6 % Lube
RT: 0.8 % Zn-st

T=2050F
t=30 min
Atm=75N2/25H2+ methan

Mix	Comp.	% gr	P tsi	GD g/cm3	DC %	SD g/cm3	HV10	HRB/*HRA*	YS ksi	TS ksi	A %	C %	O %	N %
1	WC	0,3	43	7,09	-0,12	7,08	227	94	74,3	109,7	1,9	0,26	0,109	0,055
1	WC	0,3	50	7,21	-0,09	7,21	256	97	79,9	118,0	2,1	0,27	0,119	0,054
2	WC	0,4	36	6,91	-0,11	6,90	229	93	76,6	107,2	1,2	0,36	0,086	0,056
2	WC	0,4	43	7,09	-0,06	7,07	256	97	81,7	118,0	1,5	0,35	0,100	0,054
2	WC	0,4	50	7,20	-0,05	7,19	273	98	86,0	124,8	1,6	0,35	0,111	0,052
3	WC	0,5	43	7,08	-0,04	7,05	339	*67*	95,3	122,8	0,6	0,47	0,093	0,053
3	WC	0,5	50	7,18	-0,04	7,16	367	*68*	99,9	129,1	0,6	0,48	0,103	0,053
4	WC	0,6	43	7,07	0,01	7,03	447	*75*	108,8	119,1	0,3	0,55	0,090	0,050
4	WC	0,6	50	7,16	0,03	7,13	452	*75*	114,0	133,3	0,3	0,56	0,099	0,048
5	RT	0,3	43	6,90	-0,25	6,91	201	89	67,3	97,1	1,4	0,27	0,071	0,066
5	RT	0,3	50	7,02	-0,27	7,04	221	93	72,4	103,8	1,5	0,26	0,075	0,063
6	RT	0,4	36	6,73	-0,17	6,72	198	90	66,6	92,5	1,0	0,36	0,070	0,056
6	RT	0,4	43	6,90	-0,18	6,90	218	93	73,2	101,9	1,2	0,34	0,076	0,061
6	RT	0,4	50	7,00	-0,23	7,03	253	96	80,0	113,2	1,3	0,36	0,074	0,053
7	RT	0,5	43	6,90	-0,14	6,89	290	*62*	83,3	107,9	0,6	0,45	0,069	0,054
7	RT	0,5	50	7,01	-0,17	7,01	345	*67*	92,9	115,5	0,5	0,47	0,070	0,059
8	RT	0,6	43	6,89	-0,08	6,87	423	*70*	98,5	112,8	0,3	0,57	0,066	0,054
8	RT	0,6	50	6,98	-0,11	6,98	476	*71*	102,1	120,8	0,3	0,60	0,066	0,056

Astaloy CrM RT/WC

WC: 0.6 % Lube
RT: 0.8 % Zn-st

T=1120C
t=30 min
Atm=75N2/25H2+ methan

Mix	Comp.	% gr	P MPa	GD g/cm3	DC %	SD g/cm3	HRB/*HRA*	HV10	YS MPa	TS MPa	A %	C %	O %	N %
1	WC	0,3	600	7,09	-0,12	7,08	94	227	519	766	1,9	0,264	0,109	0,055
1	WC	0,3	700	7,21	-0,09	7,21	97	256	558	824	2,1	0,267	0,119	0,054
2	WC	0,4	500	6,91	-0,11	6,90	93	229	535	749	1,2	0,356	0,086	0,056
2	WC	0,4	600	7,09	-0,06	7,07	97	256	571	824	1,5	0,349	0,100	0,054
2	WC	0,4	700	7,20	-0,05	7,19	98	273	601	872	1,6	0,349	0,111	0,052
3	WC	0,5	600	7,08	-0,04	7,05	*67*	339	666	858	0,6	0,469	0,093	0,053
3	WC	0,5	700	7,18	-0,04	7,16	*68*	367	698	902	0,6	0,480	0,103	0,053
4	WC	0,6	600	7,07	0,01	7,03	*75*	447	760	832	0,3	0,554	0,090	0,050
4	WC	0,6	700	7,16	0,03	7,13	*75*	452	796	931	0,3	0,557	0,099	0,048
5	RT	0,3	600	6,90	-0,25	6,91	89	201	470	678	1,4	0,269	0,071	0,066
5	RT	0,3	700	7,02	-0,27	7,04	93	221	506	725	1,5	0,264	0,075	0,063
6	RT	0,4	500	6,73	-0,17	6,72	90	198	465	646	1,0	0,360	0,070	0,056
6	RT	0,4	600	6,90	-0,18	6,90	93	218	511	712	1,2	0,344	0,076	0,061
6	RT	0,4	700	7,00	-0,23	7,03	96	253	559	791	1,3	0,359	0,074	0,053
7	RT	0,5	600	6,90	-0,14	6,89	*62*	290	582	754	0,6	0,450	0,069	0,054
7	RT	0,5	700	7,01	-0,17	7,01	*67*	345	649	807	0,5	0,471	0,070	0,059
8	RT	0,6	600	6,89	-0,08	6,87	*70*	423	688	788	0,3	0,568	0,066	0,054
8	RT	0,6	700	6,98	-0,11	6,98	*71*	476	713	844	0,3	0,595	0,066	0,056

Astaloy CrM RT/WC

WC: 0.6 % Lube T=2280F
RT: 0.8 % Zn-st t=70 min
Atm=90N2/10H2

Mix	Comp.	% gr	P	GD	DC	SD	HRB/HRA	HV10	YS	TS	A	C	O	N
			tsi	g/cm3	%	g/cm3			ksi	ksi	%	%	%	%
1	WC	0,3	43	7,09	-0,56	7,17	92	204	74,3	116,4	4,1	0,177	0,009	0,060
1	WC	0,3	50	7,21	-0,48	7,27	97	228	77,7	123,1	5,0	0,171	0,022	0,057
2	WC	0,4	36	6,91	-0,6	6,98	94	206	78,5	121,0	3,4	0,259	0,009	0,066
2	WC	0,4	43	7,09	-0,51	7,15	96	223	84,3	130,4	3,7	0,255	0,009	0,060
2	WC	0,4	50	7,20	-0,47	7,26	100	249	87,0	136,3	4,4	0,252	0,017	0,054
3	WC	0,5	43	7,08	-0,49	7,14	99	237	94,5	143,7	2,8	0,356	0,008	0,055
3	WC	0,5	50	7,18	-0,45	7,25	*62*	269	96,6	148,2	3,3	0,334	0,019	0,050
4	WC	0,6	43	7,07	-0,44	7,11	*66*	294	NA	NA	NA	0,440	0,012	0,049
4	WC	0,6	50	7,16	-0,43	7,21	*66*	311	118,0	186,0	1,9	0,428	0,020	0,042
5	RT	0,3	43	6,90	-0,66	6,99	91	185	64,4	96,1	2,3	0,164	0,009	0,067
5	RT	0,3	50	7,02	-0,65	7,12	94	211	70,4	106,8	2,8	0,165	0,009	0,066
6	RT	0,4	36	6,73	-0,67	6,83	90	185	67,9	101,6	2,0	0,258	0,009	0,067
6	RT	0,4	43	6,90	-0,64	6,99	91	199	74,6	113,2	2,5	0,261	0,008	0,065
6	RT	0,4	50	7,00	-0,64	7,1	97	218	79,5	121,0	2,6	0,257	0,008	0,065
7	RT	0,5	43	6,90	-0,58	6,97	97	216	82,2	121,8	1,9	0,337	0,008	0,062
7	RT	0,5	50	7,01	-0,58	7,08	99	236	87,5	130,7	2,0	0,341	0,009	0,061
8	RT	0,6	43	6,89	-0,59	6,96	*64*	255	100,9	151,6	1,2	0,411	0,010	0,057
8	RT	0,6	50	6,98	-0,59	7,07	*64*	282	107,9	167,5	1,3	0,418	0,005	0,058

Astaloy CrM RT/WC

WC: 0.6 % Lube
RT: 0.8 % Zn-st

T=1250C
t=70 min
Atm=90N2/10H2

Mix	Comp.	% gr	P MPa	GD g/cm3	DC %	SD g/cm3	HRB/HRA	HV10	YS MPa	TS MPa	A %	C %	O %	N %
1	WC	0,3	600	7,09	-0,56	7,17	92	204	519	813	4,1	0,177	0,009	0,060
1	WC	0,3	700	7,21	-0,48	7,27	97	228	543	860	5,0	0,171	0,022	0,057
2	WC	0,4	500	6,91	-0,60	6,98	94	206	548	845	3,4	0,259	0,009	0,066
2	WC	0,4	600	7,09	-0,51	7,15	96	223	589	911	3,7	0,255	0,009	0,060
2	WC	0,4	700	7,20	-0,47	7,26	100	249	608	952	4,4	0,252	0,017	0,054
3	WC	0,5	600	7,08	-0,49	7,14	99	237	660	1004	2,8	0,356	0,008	0,055
3	WC	0,5	700	7,18	-0,45	7,25	*62*	269	675	1035	3,3	0,334	0,019	0,050
4	WC	0,6	600	7,07	-0,44	7,11	*66*	294	NA	NA	NA	0,440	0,012	0,049
4	WC	0,6	700	7,16	-0,43	7,21	*66*	311	824	1299	1,9	0,428	0,020	0,042
5	RT	0,3	600	6,90	-0,66	6,99	91	185	450	671	2,3	0,164	0,009	0,067
5	RT	0,3	700	7,02	-0,65	7,12	94	211	492	746	2,8	0,165	0,009	0,066
6	RT	0,4	500	6,73	-0,67	6,83	90	185	474	710	2,0	0,258	0,009	0,067
6	RT	0,4	600	6,90	-0,64	6,99	91	199	521	791	2,5	0,261	0,008	0,065
6	RT	0,4	700	7,00	-0,64	7,1	97	218	555	845	2,6	0,257	0,008	0,065
7	RT	0,5	600	6,90	-0,58	6,97	97	216	574	851	1,9	0,337	0,008	0,062
7	RT	0,5	700	7,01	-0,58	7,08	99	236	611	913	2,0	0,341	0,009	0,061
8	RT	0,6	600	6,89	-0,59	6,96	*64*	255	705	1059	1,2	0,411	0,010	0,057
8	RT	0,6	700	6,98	-0,59	7,07	*64*	282	754	1170	1,3	0,418	0,005	0,058