New alloy designed for heat treated applications

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Abstract: Powder metallurgy is inherently a net shape process and for cost reasons secondary operations should be avoided. However, in practice it is often necessary to perform at least some machining in the soft condition after sintering in order to create the desired geometry of the part. These parts can then be heat treated in order to reach high mechanical properties. Traditional materials for heat treatment often include Copper, Nickel, or Molybdenum in quantities of totally 2-6%. In the light of the recent cost increases for these alloying elements these materials are becoming less competitive compared to solid steel process routes. Recently a new iron powder was introduced that is designed to perform well in heat treatment and having a lean alloy composition. The present work compares the performance of this powder to some powders commonly used in heat treated applications.

Introduction

Alloying elements commonly used in materials intended for heat treatment are Molybdenum, Nickel, and Copper. The fluctuations in raw material prices for these elements have in recent years been relatively volatile, making material cost predictions difficult. Figure 1 illustrates the variations in raw material price for Ni, Mo and Cu over the last years. Distaloy AQ is a new low alloyed material intended for heat treatment purposes for powder metallurgical component manufacturing. The composition is Fe-0.5Ni-0.5Mo, where the base powder is pure iron, and Ni and Mo have been diffusion bonded; a technology that is a patented robust process of Höganäs AB and has been consistently preferred by customers for quality. The low alloying content of Distaloy AQ makes it less sensitive to price fluctuation and ensures a robust product from an economical point of view.

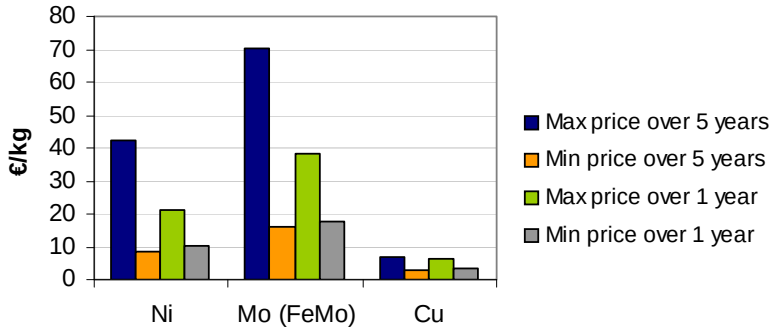


Figure 1. Variations in raw material price over 5 and 1 years period of time.

The alloying level of Distaloy AQ gives good machinability and sizing properties in sintered state, but still provides enough hardenability for high strength after heat treatment; a very favourable combination of properties as generally some machining is necessary in the soft state. This should be compared to traditional materials for heat treatment, with relatively high alloying content, where martensite formation already after sintering complicates sizing and machining operations.
The diffusion alloying process allows for maximum compressibility and strength together with good consistency of properties on the PM components. In Figure 2 the compressibility of Distaloy AQ for lubricated die and for some mixes with graphite and lubricant can be found. The possibility to reach high densities is beneficial for mechanical performance and it is also a favourable property for a heat treatment material, as it makes it easier to control carbon

penetration in a case hardening process; something that can be complicated for a material with high porosity.

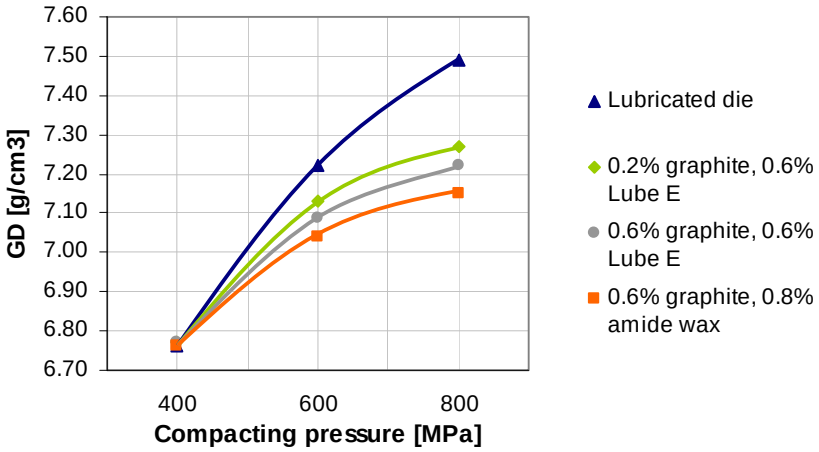


Figure 2. Green density of Distaloy AQ for lubricated die and for some different mixes with graphite and lubricant.

The combination of different material performance characteristics is always sensitive to the alloying content, and it is important to look at the complete picture when material is selected. This paper will demonstrate the use of the new material in different processes; sintering, C-neutral Q&T, and case hardening, and compare with other alloys commonly used in heat treatment processes. From the results it is clear that there are cases where it is advantageous with a low alloying content, not only for cost reasons.

Experimental

Mixes were made with natural graphite (C-UF4) ranging from 0.2-0.8%, and 0.6% Lube E as lubricant. For machinability trials (drilling), mixes with 0.5% MnS as machinability-enhancing additive were prepared.
Compaction was performed at 600 MPa, and at 700 MPa/70ºC.
Tensile testing bars (ISO 2740) and fatigue bars (ISO 3928) were used in the investigation. Cylindrical specimens with dimensions Ø25 x 20 mm and Ø64 x 35 mm were produced to investigate the mass effect, and Ø80 x 12 mm specimens were produced for machinability tests.
Sintering was performed at 1120ºC for 30 minutes in an atmosphere of 90/10 N_2/H_2, and at 1250ºC for 1h in 90/10 N_2/H_2. No forced cooling was applied.
For heat treatments specimens were austenitized at 920ºC for 20 minutes at different C-potentials to create both through hardening and case hardening. Oil quench was applied with an oil temperature of 60ºC. The specimens were then tempered at 200ºC for 1h in air.

Results and discussion

Sintered properties

As mentioned, the material is intended for heat treatments. In sintered state it performs approximately at the same level as Fe-2Cu-C. The hardness and strength level as sintered makes it an excellent material for sizing and machining prior to heat treatment. Another advantage with the material is a relatively stable dimensional change over a wide carbon range. The sintered density, dimensional change, hardness tensile strength and elongation of the material after sintering are presented in Figures 3-5.

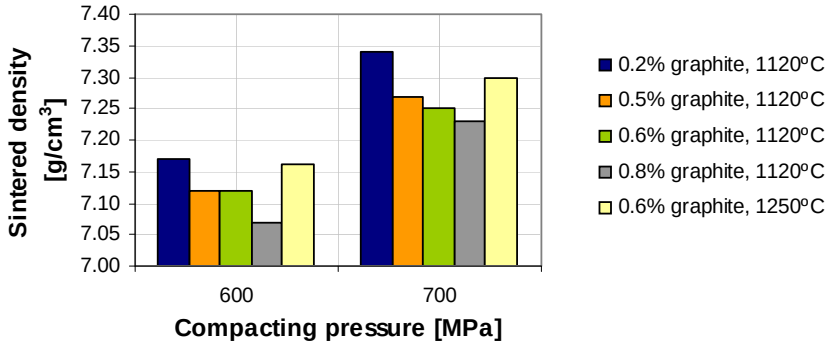


Figure 3. Sintered density for different graphite levels and compacting pressure. 0.6% Lube E used as lubricant.

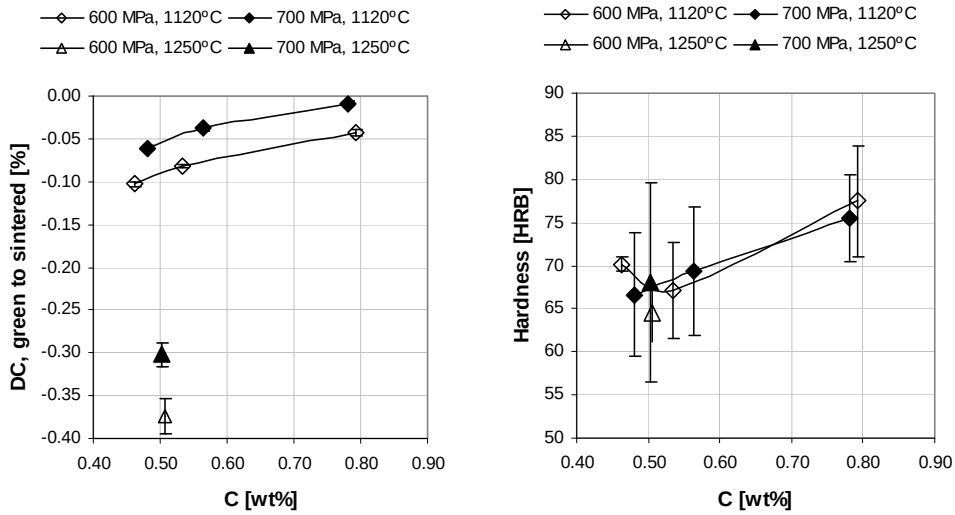


Figure 4. Dimensional change, green to sintered (left), and hardness (right) after sintering.

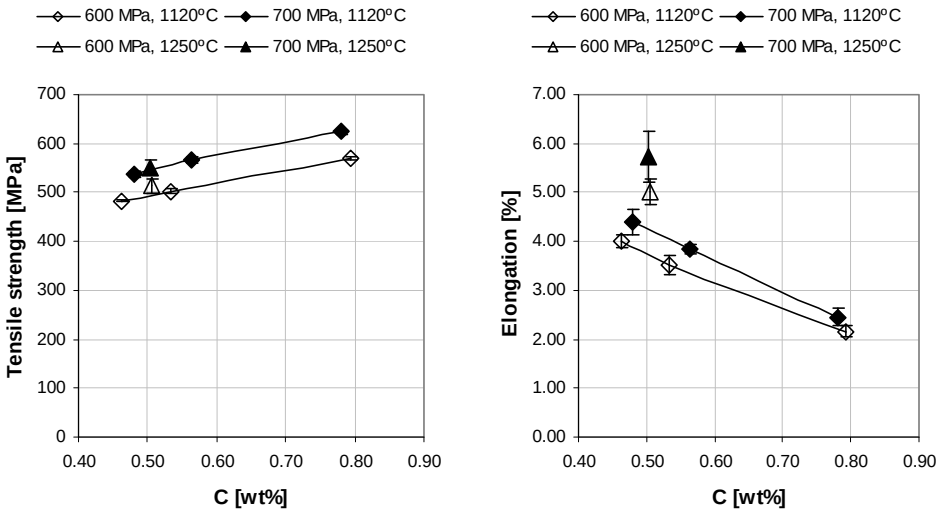


Figure 5. Tensile strength (left) and elongation (right) after sintering.

Heat treated properties

Figures 6-8 demonstrates the mechanical performance after C-neutral Q&T. As can be seen, very high strength and hardness can be reached. The figures also show the very positive response for high density and high temperature sintering. The material has a strength maximum around 0.5-0.6% C. Hardness increases with C-content, while elongation drops. For the highest carbon levels both yield strength and elongation was difficult to determine. Elongation values are therefore somewhat uncertain, and since yield strength and tensile strength are very close at this carbon level, the more accurate tensile strength values are displayed for an approximate C-dependence.

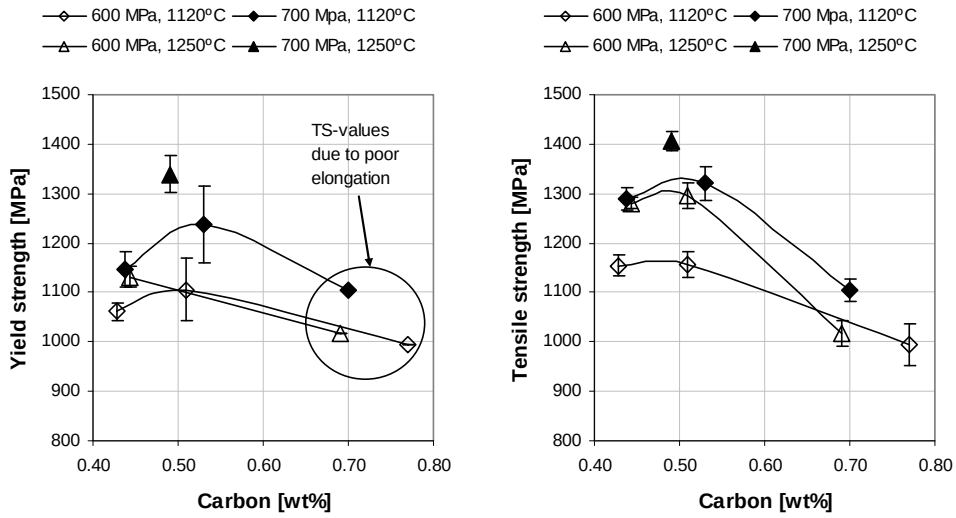


Figure 6. Yield strength (left), and tensile strength (right) after Q&T, through hardening.

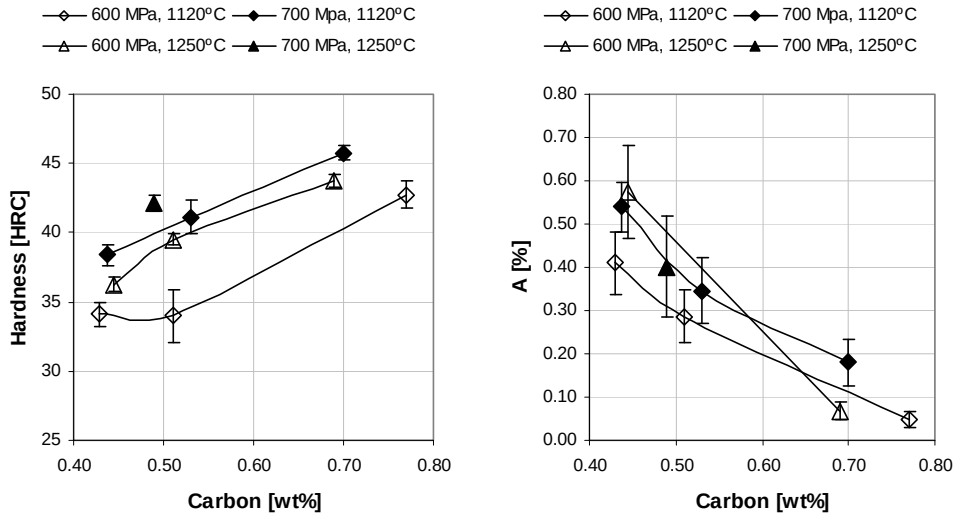


Figure 7. Hardness (left), and elongation (right) after Q&T, through hardening.

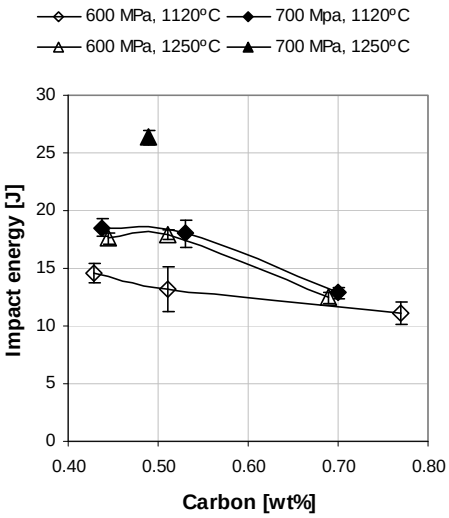


Figure 8. Impact energy after Q&T, through hardening.

When case hardening was applied, the static mechanical performance found was similar to that of the through hardened low-C specimens. As will be shown, the advantage with case hardening is instead found in an increase in dynamic performance. Figure 9 shows the hardness profiles obtained after case hardening of Distaloy AQ. At low density the carbon penetration was too deep, and no well defined gradient was achieved. In Table 1 a summary of the static properties can be found.

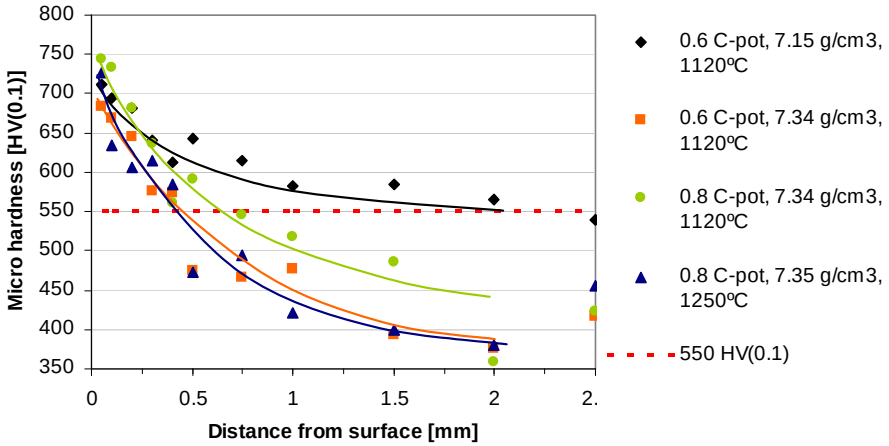


Figure 9. Hardness profiles for some of the materials tested. The trend lines are hand drawn and added only to facilitate the interpretation of the diagram.

Table 1. Mechanical performance of case hardened Distaloy AQ

	Hardness [HRC]		Tensile strength [MPa]		Elongation [%]		Impact energy [J]	
C-pot	0.6	0.8	0.6	0.8	0.6	0.8	0.6	0.8
7.15g/cm^3, 1120ºC	32	33	1104	1061	0.47	0.32	12	12
7.34g/cm^3, 1120ºC	33	32	1157	1097	0.60	0.38	15	14
7.20g/cm^3, 1250ºC	33	33	1117	1060	0.48	0.33	13	12
7.34g/cm^3, 1250ºC	30	30	1108	1046	0.61	0.49	17	16

Fatigue

Fatigue was tested according to ISO3928 plane bending fatigue. Evaluation of data was performed according to MPIF Standard 56. Table 2 shows the results from the study. For the dynamic properties, case hardening is beneficial. With high density and high temperature sintering a fatigue limit over 500 MPa can be reached. After conventional sintering, it is still in the 500 MPa range. Case hardening with a C-pot of 0.6 instead of 0.8 generally lowers the σ50 value with approx. 15 MPa, and the σ90 with approx. 30 MPa.

Table 2. Fatigue data for Distaloy AQ, case hardened and through hardened, and for some reference materials.

Material	Graphite [%]	Density [g/cm^3]	Sintering temp.[ºC]	C-pot [%]	HRC	σ50 [MPa]	σ [MPa]	σ 90 [MPa]
D-AQ	0.2	7.15	1120	0.8	32	460	48	395
D-AQ	0.2	7.34	1120	0.8	32	497	<10	484
D-AQ	0.2	7.35	1250	0.8	30	520	20	492
D-AQ	0.6	7.16	1120	0.6	34	391	<10	372
D-AQ	0.6	7.29	1120	0.6	41	350	<10	335
D-AB	0.2	7.13	1120	0.8	30	477	27	441
D-AB	0.2	7.30	1120	0.8	31	489	14	470
D-AB	0.6	7.25	1120	0.6	40	356	30	315
D-AE	0.2	7.34	1250	0.8	30	489	19	461

Machining

The machinability in sintered state was investigated by a drill test. The materials tested were Distaloy AQ and Distaloy AE, with and without the addition of MnS as machinability-enhancing additive. The drill used was a Dormer Ø3.5 mm, A002, and the geometry of the test specimens was Ø80 x 12 mm. A cutting speed of = 40 m/min and a feeding rate of 0.06 mm/rev was applied. The cutting depth was 9.6 mm, and the drilling was performed dry. The machinability criterion was number of drilled holes before total drill failure. The results are found in Table 3. As can be seen in the table the statistics is rather poor, but this is not the complete truth. Several drills were used at lower cutting speed and feeding rate, without reaching failure. Finally the settings above, which should be considered quite tough, were used. Even so, when Distaloy AQ with MnS addition was machined, no drill failure could be reached within a reasonable testing time. The number of holes possible to drill with MnS added should therefore be considered to be much larger than what was obtained without MnS.

The results indicate that the 0.6 C-content Distaloy AQ is easier to machine than the 0.2 C material. This is reasonable since at 0.6 C the structure will be mainly pearlitic, almost no martensite will form after sintering, there is little increase in bainite content, and at the same time the ferrite content will be very low. At 0.2 C the microstructure will be more mixed, with high levels of ferrite. Such a mixed structure can be unfavourable for machining. In Distaloy AE, the effect of C is the opposite. The reason here is that at high C-levels, martensite will form after sintering. As can be seen in the table, this has a considerable effect, and the difference in machinability between Distaloy AQ and Distaloy AE at high C-content is huge.

Table 3. Results from machinability test. Specimens sintered at 1120ºC.

Base powder	Graphite [%]	MnS [%]	# holes/drill	Used drills	Time [min]
Distaloy AQ	0.2	-	1000	1	33
Distaloy AQ	0.6	-	2400	1	79
Distaloy AE	0.2	0.5	1500	1	49
Distaloy AE	0.6	0.5	20	4	1

Microstructure

There is a large difference in microstructure after sintering between Distaloy AQ and more highly alloyed materials, such as Distaloy AE, where Distaloy AQ contains much lower

amount of martensite. A comparison of Distaloy AQ at different carbon contents, sintered at 1120°C, showed a significant increase of pearlite with increasing carbon content, see figure 10. An increase of martensite or bainite due to the increase of carbon content is hard to distinguish.
After Q&T TS bars of Distaloy AQ are martensitic, the only difference compared to Distaloy AE is a smaller amount of Ni-rich austenite spots (Figure 11). Distaloy AQ is, however, because of the low alloying content, more sensitive to cooling rate. An effect is that massive sections of Distaloy AQ will have a more ductile core after Q&T, see table 4.

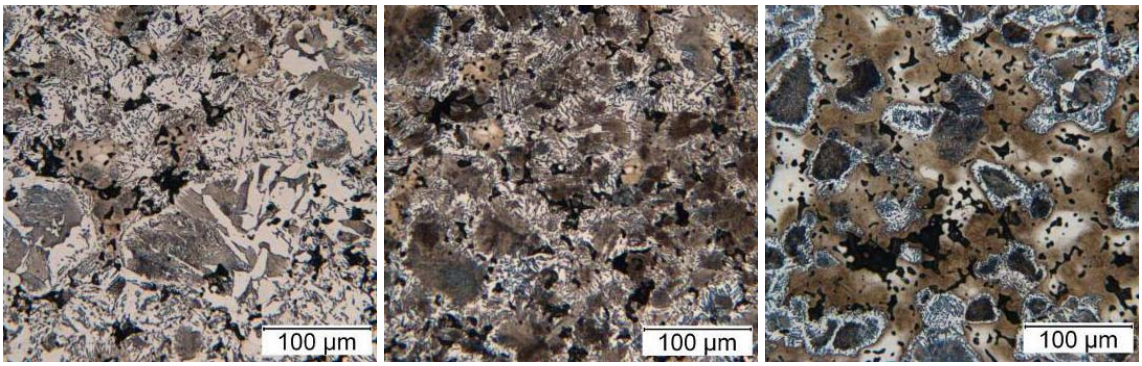


Figure 10. Distaloy AQ 0.5% C (left), 0.8% C (middle), Distaloy AE 0.6%C (right). Sintered at 1120°C. (Ferrite-white, pearlite-grey, martensite-brown, Ni-rich austenite-bright spots).

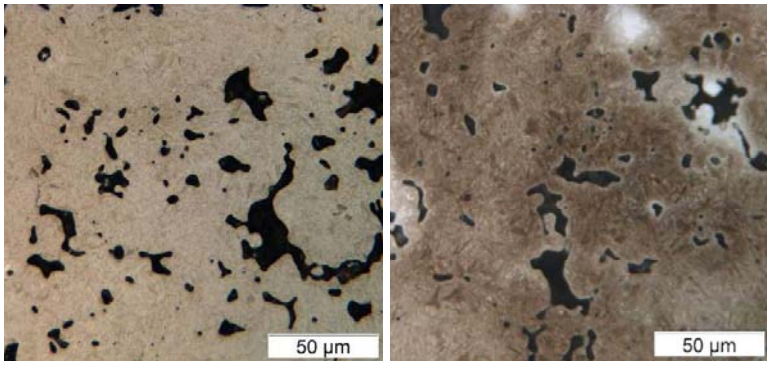


Figure 11. Heat treated Distaloy AQ (left), Distaloy AE (right), 0.6% C. The microstructure is martensite in both cases.

Table 4. Mass effect on martensite content after Q&T, 0.6% C, through hardened.

	Distaloy AQ, martensite content [%]		Distaloy AE, martensite content [%]	
	Surface	Centre	Surface	Centre
TS-bar	100	100	100	100
Ø25 x 20 mm	100	45	100	85
Ø64 x 35 mm	>90	15	100	75

Competitive comparison

In figure 12 a comparison of different Q&T (through hardened) materials at a carbon level of 0.6 can be found. Characteristic for Distaloy AQ is a superior yield strength, high tensile strength, high hardness, and relatively low elongation. The differences in performance after Q&T between the materials can to a large extent be related to the nickel content. The small amount of soft Ni-rich austenite spots in Distaloy AQ results in a high hardness. At the same time, the low Ni-content will also reduce the elongation of the material. Still, the alloying content is sufficient for martensite formation with a high tensile strength, and connected to the low elongation, the yield strength will be very high.

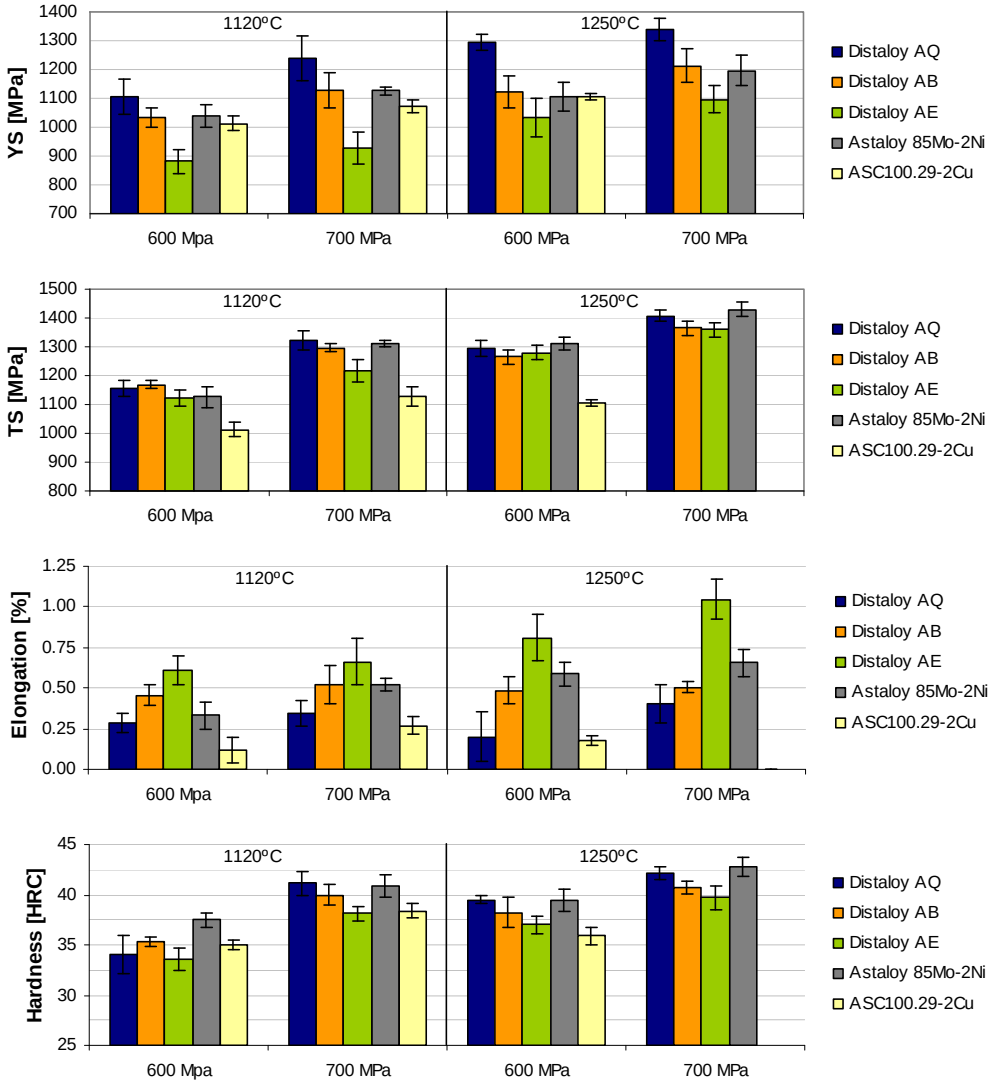


Figure 12. Comparison of some materials commonly used in heat treated applications.

Conclusions

- Low alloying content route with new diffusion alloyed Fe-0.5Ni-0.5Mo powder offers cost effective robust solutions for high mechanical performance after heat treatment.
- Stable dimensional change after sintering is obtained over a wide carbon range
- Sintered microstructure with high pearlitic content offers good sizing and machining possibility.
- Strength and hardness after quench and tempering is on the same level as for traditional, more highly alloyed materials used in heat treated applications.
- High compaction pressure and high temperature sintering have positive effect on mechanical performance, and by combining them excellent properties can be reached. With 700 MPa compaction, 1250ºC sintering, and Q&T, a hardness above 40 HRC in combination with a tensile strength of 1400 MPa, and an elongation of 0.4% has been reached.
- Case hardening improves dynamic properties, and with 700 MPa compaction a fatigue limit over 500MPa can be reached.