SINTERED IRON-BASED MATERIALS

This chapter deals with the characteristics of sintered iron-based materials for the industrial production of structural parts with closely controlled dimensional and physical properties.
# 9. SINTERED IRON-BASED MATERIALS

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9.1 General aspects

There are several ways to achieve desired strength properties with iron-based sintered materials. The most important parameters of influence are:

- Density
- Sintering conditions
- Alloying elements
- Heat-treating conditions

These parameters should be controlled within the closest possible limits, because even small variations may cause unacceptably wide scatter of dimensional changes during sintering and thus spoil the dimensional stability of the sintered parts.

Density is of prime importance with respect to the physical properties of sintered structural parts, because tensile strength and fatigue strength increase in approximate linear proportion, elongation and impact strength exponentially, with sintered density. See schematic diagram at Fig. 9.1.
Sintered density mainly depends on compact density which, in turn, depends on compacting pressure. Compacting pressures higher than about 650 N/mm$^2$ are not normally practiced because of the risk of over-stressing the compacting tool. With maximum pressing loads tolerable under mass production conditions (600 - 650 N/mm$^2$), densities up to 7.1 - 7.2 g/cm$^3$ are achievable. This density range can be extended up to 7.3 - 7.4 g/cm$^3$ when utilizing a warm-pressing technique recently developed by HÖGANÄS AB [9.1].

Densities up to 7.5 - 7.6 g/cm$^3$ can only be achieved by pre-sintering and re-pressing the compacts before final sintering (chapter 7, § 7.2). Still higher densities, up to 7.7 - 7.8 g/cm$^3$, can be achieved by means of hot-forging pre-pressed (and pre-sintered) compacts [9.2].

**Sintering conditions** decide about (1) how fast and efficient powder particles in the compact weld together and pores get rounded, (2) how fast homogenization of alloying elements takes place (chapter 6, § 6.2), and (3) whether sensitive alloying elements oxidize or not (chapter 6, § 6.4).

In iron powder metallurgy, sintering is most commonly carried out in continuous mesh-belt furnaces operating at 1120 to max. 1150°C. Sintering temperatures of 1250 - 1350°C would substantially accelerate the homogenization of alloying elements and allow the use of beneficial but oxygen-sensitive alloying elements like chromium and manganese. However, except for high-priced special materials, such high sintering temperatures are prohibitive for economical reasons. Mesh-belt furnaces cannot withstand temperatures above 1150°C anyway.

Time at temperature is usually not longer than 20 to 30 minutes, since longer sintering times yield only marginally improved properties which do not justify the increased sintering costs.

**Alloying elements** dissolved in the base metal, give rise to the formation of various microstructures and increase the material's resistance to deformation. See Fig. 9.2a. Alloying elements also influence the dimensional change of structural parts during sintering. Alloying elements are indispensable with respect to the hardenability of conventional as well as sintered steels. See Fig. 9.2b.
Figure 9.2. Influence of alloying elements upon tensile strength (a) and hardenability (b)
In principle, alloying elements have the same effect on sintered steels as on conventional steels. However, not all alloying elements common in conventional steels can be utilized in sintered steels because some of them, as e.g. Cr, Mn, and V, are too easily oxidized in commercial sintering atmospheres (chapter 6, § 6.4). On the other hand, elements undesirable in conventional steels, like e.g. phosphorous ("blue brittleness"), can have beneficial effects on sintered steels (chapter 6, § 6.2.4).

Alloy compositions of sintered steels for structural parts have to be carefully selected not only with respect to desired strength but also with respect to dimensional stability during sintering. With alloy compositions yielding hardness levels above 150 - 180 HV, it is important that dimensional changes of the structural parts during sintering are as small as possible and, even more important, that the scatter of these dimensional changes is kept within the closest possible limits.

While parts with hardnesses up to 150 HV can be sized or coined fairly easily, sizing or coining becomes increasingly difficult and eventually impossible the more their hardness exceeds this level. In the mass production of high-strength high-precision parts, it is therefore important that dimensional changes during sintering (and subsequent heat-treatment) are insensitive to the small unavoidable variations in process parameters and material composition.

Heat-treating conditions, when applied to sintered steel components, must be especially well controlled to ensure the highest possible degree of dimensional stability of the component in the hardening and tempering procedure. Asymmetric cooling during quenching of a sintered component, especially when of complex shape, may lead to distortions so severe that the part must either be rejected or subjected to expensive re-machining which would wipe out the cost advantage of P/M technology over conventional production methods.

Dimensional stability of the sintered parts depends on the accuracy with which the above mentioned parameters can be controlled. Two examples shown at Fig. 9.3 illustrate the influence of small variations in compact density, sintering conditions and powder composition on the dimensional changes of sintering. It can be seen from these examples that intelligently chosen types and amounts of alloying elements can make dimensional changes of sintered compacts less sensitive to varying processing parameters.
Figure 9.3. Influence of variations in compact density, sintering conditions and powder composition on dimensional changes during sintering.
9.2 Alloying Systems, Microstructures and Properties

In the majority of cases, sintered iron and steel components are to-day made of materials based on one or the other of the following alloying systems:

- Plain Iron
- Iron - Carbon
- Iron - Copper
- Iron - Copper - Carbon
- Iron - Phosphorus - Carbon
- Iron - Copper - Nickel - Carbon
- Iron - Copper - Nickel - Molybdenum - Carbon

Normally, these materials are mechanical mixtures of plain iron powder with the respective elements and some lubricant in powder form. Such mixtures can be compacted much more easily than fully pre-alloyed powders. However, mechanical powder mixtures tend to segregate when transported and handled. Therefore are many of these materials today available in the form of partially pre-alloyed non-segregable press-ready powder mixes known under the trade-names Distaloy and Star-Mix (chapter 3).

Microstructures of sintered alloyed steels, produced from powder mixes, are typically much more heterogeneous than those of conventional alloyed steels. While carbon diffuses very rapidly in the basic iron powder and soon reaches equilibrium during sintering, other alloying elements like copper, nickel, and molybdenum diffuse much more slowly and would reach equilibrium only after extremely long sintering times (chapter 6, Fig. 6.9). Hence, produced under commercially acceptable sintering conditions, these materials will always exhibit a certain degree of heterogeneity.

9.2.1 Plain Iron

Ever since the late 1930’s, when powder metallurgy methods were first being utilized on a larger industrial scale in Europe and in the USA, self-lubricating bearings and sintered structural parts for low-strength and soft-magnetic applications have been produced from plain iron powders. Fig. 9.4 shows the microstructure of a plain sponge iron powder (N C100.24) compacted with 690 N/mm² to a density of 7.03 g/cm³.
Figure 9.4 Microstructure of NC100.24, compacted with 690 N/mm² and sintered 30 min at 1120°C. Sintered density: 7.03 g/cm³.
Fig. 9.5 shows the microstructure of a plain atomized iron powder (ABC 100.30) compacted with 392 N/mm² to a density of 6.88 g/cm³. Both materials have been sintered for 30 min at 1120°C in dissociated ammonia (75%H₂+25%N₂).

Despite comparable densities and identical sintering conditions, the two materials differ significantly with respect to both grain size and pore structure, the NC 100.24-material having a smaller grain size and a more finely dispersed pore structure than the ABC 100.30-material. Note that a considerably lower compacting pressure was sufficient to compact ABC 100.30 to almost the same density as NC 100.24.

Grain size is a parameter which has an important influence upon the physical properties of plain iron. With decreasing grain size, strength generally increases, but with increasing grain size, ductility and soft-magnetic properties are improving. Finely dispersed pores have a greater negative effect on soft-magnetic properties than coarser pores. Thus, for high-density soft-magnetic applications, ABC 100.30 is a good choice. On the other hand, NC 100.24, because of its superior green strength after compacting, is the better choice for self-lubricating bearings with high porosity and for complex low-to medium-strength structural parts. In order to achieve strength levels above 200 N/mm² with plain sintered iron, densities above 7.2 g/cm³ are necessary, and structural parts will usually have to be re-pressed and re-sintered.
Figure 9.5. Microstructure of ABC100.30 compacted with 392 N/mm² and sintered 30 min at 1120°C. Sintered density: 6.88g/cm³.
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9.2.2 Iron - Carbon

A very efficient way to boost tensile strength and hardness of sintered iron is to alloy it with carbon. Most conveniently, this is achieved by adding graphite powder to the iron powder before compacting and sintering. Being an interstitial alloying element, carbon dissolves very rapidly in the iron powder structure during sintering. However, successful sintering of carbon containing materials requires a very carefully controlled non-decarbonizing sintering atmosphere (chapter 6, § 6.4).

Fig. 9.6 shows the microstructures of two sintered iron-carbon steels containing 0.2 and 0.5 wt.-% dissolved carbon respectively. Areas of pearlite and ferrite are clearly visible. Both materials were compacted with 589 N/mm² (6 t/cm²) from atomized iron powder (ASC100.29), sintered for 30 min at 1120°C in endogas, and having a sintered density of 7.15 and 7.10 g/cm³ respectively.

Apart from the presence of pores, these microstructures are practically identical with those of corresponding conventional plain carbon steels. The effect of dissolved carbon on tensile strength, elongation and dimensional change of sintered iron is shown in the diagram at Fig. 9.7. In sintered as well as in conventional carbon steels, carbon contents above 0.8 wt.-% produce a brittle cementite network in the former austenite grain boundaries and should be avoided.
Figure 9.6. Microstructures of (a) ASC100.29 + 0.2\%C and (b) ASC100.29 +0.5\%C, both materials compacted with 589 N/mm² and sintered 30 min at 1120°C. Sintered densities 7.15 and 7.10 g/cm³.
Figure 9.7. Influence of carbon content upon the properties of sintered iron.
9.2 ALLOYING SYSTEMS, MICROSTRUCTURES AND PROPERTIES

9.2.3 Iron - Copper, Iron - Copper - Carbon

Mixtures of iron and copper powder have a twofold benefit:
1. Copper melts at 1094°C, i.e. below sintering temperature, and rapidly infiltrates the pore system of the compact from where it diffuses relatively easily into the iron powder particles.
2. Copper is dissolvable in γ-iron (austenite) up to approx. 9 wt.-%, but only up to 0.4 wt.-% in α-iron (ferrite); consequently, iron-copper alloys can be precipitation-hardened by low-temperature annealing after sintering - and actually do so to a certain extend already on passing the cooling zone of the sintering furnace.

Copper is added to the basic iron powder usually in amounts from 1.5 to 4 wt.-%. Fig. 9.8 shows the microstructures of two iron-copper materials containing 2 and 4 wt.-% admixed copper respectively, compacted to densities of approx. 7 g/ cm³, and sintered for 30 minutes at 1120°C. As can be seen, the copper is not completely homogeneously distributed in the iron matrix after sintering.

Regions of higher copper concentration appear on the micrographs as brownish seams along grain boundaries and former iron particle surfaces.
Figure 9.8. Microstructures of (a) ASC100.29 + 2%Cu and (b) ASC100.29 + 4%Cu, both materials compacted with 690 N/mm² and sintered 30 min at 1120°C. Sintered densities: 7.05 and 6.88 g/cm³.
With copper contents higher than about 2.5 wt.-%, compacts tend to grow to such extend during sintering that their dimensional tolerances are difficult to control. To maintain, during sintering, the dimensional stability of copper-containing structural parts, suitable amounts of graphite are added to the iron-copper powder mix. The carbonizing effect of graphite during sintering counteracts the growth-producing effect of copper (chapter 6, Fig. 6.18).

A further beneficial effect of these graphite additions is an additional increase in strength. The diagram at Fig. 9.9 illustrates the effect of carbon additions on tensile strength, elongation and dimensional changes of sintered iron-copper materials.
Fig. 9.10 shows the microstructures of two iron-copper materials containing 2 wt.-% copper and 0,2 resp. 0,6 wt.-% carbon, compacted to densities of approx. 6,9 g/cm³, and sintered for 30 minutes at 1120°C in endogas. On the micrograph taken of the material with 0,2 wt.-% carbon, it appears that dissolved copper concentrates in carbon.
rich areas of the iron structure where it has partly disintegrated the pearlite. It is likely that copper, during heating-up to sintering temperature, has preferably penetrated the boundaries between ferrite and cementite lamellae, while austenitization of pearlitic areas was delayed (chapter 6, § 6.2.3). In the material with 0.6 wt.-% carbon, copper appears to be more homogeneously distributed.

Figure 9.10. Microstructures of (a) SC100.26 + 2%Cu + 0.2%C and (b) SC100.29 + 2%Cu + 0.6%C, both materials compacted with 490 N/mm² and sintered 30 min at 1120°C. Sintered densities: 6.84 and 6.86 g/cm³.
9.2.4 Iron - Phosphorus - Carbon

In conventional steel-making, phosphorous is a most undesirable element since it provokes irreparable segregation during solidification which make the steel brittle. In iron powder metallurgy, however, phosphorus has proven to be a very potential strength-increasing alloying element. Here, phosphorous is normally added to iron powder as a very finely ground Fe₃P-powder which, compared with other phosphorous compounds, is relatively soft and less harmful to compacting tools.

During sintering, phosphorous and iron form a eutectic melt (10% P, 1050°C) which rapidly infiltrates the pore system of the compact and enhances the sintering process (see chapter 6, Fig. 6.15).

The diagram at Fig. 9.11 shows the influence of phosphorus and carbon upon tensile strength, elongation and dimensional change. A comparison of this diagram with the one at Fig. 9.9 is most interesting. In both cases, the basic iron powder is NC100.24. As can be seen, additions of 0.3 to 0.6% phosphorus have a very similar effect on tensile strength and elongation as additions of 2 to 4% copper. However, phosphorus additions affect the dimensional change during sintering to a much lesser degree than copper additions and produce shrinkage rather than growth of the sintered parts.
Fig. 9.12 shows the micrographs of two sintered materials containing 0.45% phosphorus, one without and one with 0.5% carbon. Note the rounded-off pores of medium size and the absence of small pores.

Figure 9.11 Influence of phosphorus and carbon additions upon the properties of sintered iron materials.
Figure 9.12. Microstructures of (a) NC 100.24 + 0.45%P and (b) NC 100.24 + 0.45%P + 0.5% C, both materials compacted with 690 N/mm² and sintered 30 min at 1120°C. Sintered densities: 7.13 and 6.93 g/cm³.
This particular pore structure has a very beneficial influence on impact strength - a phenomenon which can be explained in terms of a substantially reduced notch effect. See Fig. 9.13.

Figure 9.13 Influence of phosphorus additions upon impact strength of sintered iron materials.
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9.2.5 Iron - Copper - Nickel - Carbon

Adding nickel to iron-copper and iron-copper-carbon mixes has approximately the same effect on tensile strength and elongation as increasing the copper content. However, the essential advantage in substituting some of the copper with nickel is a considerable reduction of the dimensional change during sintering.

See Fig. 9.14 where tensile strength, elongation and dimensional change of sintered parts, made of mixes containing varying amounts of copper and nickel, are shown in comparison.

Figure 9.14 Influence of varying proportions of nickel and copper additions upon the properties of sintered iron materials.
9.2 ALLOYING SYSTEMS, MICROSTRUCTURES AND PROPERTIES

Fig. 9.15 shows the microstructures of two sintered iron-based materials, one containing 2.5% Cu+2.5% Ni, and the other containing 2.5% Cu+2.5% Ni+0.6% C. On the microstructure of the carbon-free material, seams of copper- and nickel-rich austenite appear along former particle surfaces from where copper and nickel have diffused into the iron particles during sintering.

On the microstructure of the carbon containing material, apart from ferrite and pearlite, small areas of nickel-rich austenite appear in the neighborhood of pores and former particle surfaces. Locally, the nickel concentration is so high, that the normal cooling rate after sintering was sufficient to produce small spots of martensite.
9. SINTERED IRON-BASED MATERIALS

Figure 9.15: Microstructures of (a) SC100.26 + 2,5%Cu + 2,5%Ni and
(b) NC100.24 +2,5%C + 2,5%Ni + 0,6% C, both materials compacted with 690 N/mm² and sintered
30 min at 1120°C. Sintered densities: 7,10 and 6,96 g/cm³.
9.2.6 Iron - Copper - Nickel - Molybdenum - Carbon

Höganäs has developed a variety of materials containing Mo in combination with Ni or Cu, or both Ni and Cu, which have proven very successful in the production of structural parts for high-strength and high-accuracy applications. Some of these materials are homogenous alloys with the trade-name Astaloy, but most of them are partially pre-alloyed non-segregable powder mixes with the trade-name Distaloy.

Mixed with appropriate amounts of graphite, Astaloy- and Distaloy-materials, yield high strength properties, show good dimensional stability during sintering, and respond very well to subsequent heat-treatment. The most common of these materials are listed and briefly characterized below.

**Astaloy Mo** is an atomized iron powder homogeneously alloyed with 1.5% Mo. It has high compressibility (only slightly lower than unalloyed atomized iron powder), and fair green-strength. With carbon additions of 0.2 to 0.6%, it has excellent hardenability.

**Astaloy 85 Mo** is an atomized iron powder homogeneously alloyed with 0.85% Mo. It has high compressibility (only slightly lower than unalloyed atomized iron powder), and fair green-strength. With carbon additions of 0.2 to 0.6%, it has very good hardenability.

**Distaloy SA** is based on the sponge iron grade SC100.26 to which 1.75%Ni, 1.5%Cu and 0.5%Mo have been diffusion-bonded. Being based on sponge iron powder, this material has high green-strength. Mixed with appropriate amounts of graphite it yields high strength after sintering and responds well to subsequent heat-treatment.

**Distaloy AB** has the same chemical composition as Distaloy SA but is based on the atomized iron powder grade ASC100.29. Being based on atomized iron powder, it has high compressibility. Mixed with appropriate amounts of graphite it yields high strength after sintering and responds well to subsequent heat-treatment.

**Distaloy SE** is based on the sponge iron grade SC100.26 to which 4%Ni, 1.5%Cu and 0.5%Mo have been diffusion-bonded. Being based on sponge iron powder, it has high green-strength. Mixed with appropriate amounts of graphite it yields high strength after sintering and responds very well to subsequent heat-treatment.

**Distaloy AE** has the same chemical composition as Distaloy SE but is based on the atomized iron powder grade ASC100.29. Being based on atomized iron powder, it has high compressibility. Mixed with appropriate amounts of graphite it yields high strength after sintering and responds very well to subsequent heat-treatment.

**Distaloy DC-1** contains 2.1%Ni and 1.5%Mo, and is produced by diffusion-bonding 2.1%Ni-powder to Astaloy Mo, an atomized iron powder homogeneously alloyed with 1.5%Mo. This material is especially designed to achieve very closely restricted
dimensional scatter of the sintered components, irrespective of compact density. This makes the material ideal for components of intricate shape with internal density variations. With admixed graphite, this material ensures high strength after sintering as it forms a relatively large amount of bainite, and some martensite at the low cooling rates (0.5 - 0.8°C/s) in the cooling zone of a common belt furnace. (The letters DC stand for “Dimensional Control”).

**Distaloy DH-1** contains 2% Cu and 1.5% Mo, and is produced by diffusion-bonding 2% Cu-powder to Astaloy Mo. Admixed with graphite, this material can be transformed into a very hard martensitic-bainitic microstructure directly from sintering heat, when the belt furnace is equipped with a convective cooling system allowing cooling rates of 4 - 8°C/s. With these cooling rates, tensile strength values up to 1100 N/mm² (sintered density 7.0 g/cm³) are achievable. (The letters DH stand for “Direct Hardening”).

**Distaloy HP-1** contains 4% Ni, 2% Cu and 1.4% Mo, and is produced by diffusion-bonding 4% Ni-powder and 2% Cu-powder to Astaloy Mo. Because of its high nickel content, this material, admixed with graphite yields approx. 2 - 3% retained austenite. The combination of nickel and copper results in a dimensional change close to zero. Due to its high alloy content, the material has very high strength after sintering. Common sintering conditions and cooling rates in belt furnaces produce a microstructure of martensite and bainite. Tensile strength values between 950 and 1000 N/mm² (sintered density 7.0 g/cm³) can be achieved. (The letters HP stand for “High Performance”).

The diagram at Fig. 9.16 shows the influence of varying additions of copper and carbon on the sintered properties of Astaloy Mo.
Figure 9.16 Influence of copper and carbon additions upon the properties of sintered iron materials pre-alloyed with molybdenum (Astaloy Mo).
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Typical properties of Distaloy materials (with carbon additions) are shown in Table 9.1 and Table 9.2.

Table 9.1 Typical properties of Distaloy-materials

compacted (0.6 % Kenolube) with 600 N/mm², sintered 30 min. at 1120°C in endogas

<table>
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<tr>
<th></th>
<th>SA + 0.5 % C</th>
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<th>AB + 0.6 % C</th>
<th>AE + 0.5 % C</th>
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<tr>
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<td>15</td>
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<tr>
<td>[N/mm²]</td>
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<td>Heat-treated*</td>
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<tr>
<td>Heat-treated*</td>
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<tr>
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<tr>
<td>Heat-treated*</td>
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<tr>
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<tr>
<td>[N/mm²]</td>
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<td>Green - as</td>
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<tr>
<td>sintered [%]</td>
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<tr>
<td>Green - as</td>
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<td>heat-treated [%]</td>
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* austenitized at 915 °C, oil-quenched, tempered for 1 h at 175 °C.
** plane bending (R=1), 50 % of specimens broken after 2 x 10⁶ cycles; sintered density: 7.10 g/cm³.
9.2 ALLOYING SYSTEMS, MICROSTRUCTURES AND PROPERTIES

Table 9.2 Typical properties of Distaloy-materials

compacted (0.6 % Kenolube) with 600 N/mm², sintered 30 min at 1120 °C in endogas

<table>
<thead>
<tr>
<th></th>
<th>DC + 1 + 0.5% C</th>
<th>DH + 1 + 0.5% C</th>
<th>HP + 1 + 0.5% C</th>
<th>Heat-treated* (0.4% C)</th>
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<td>Compressibility [g/cm³]</td>
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<td>7.10</td>
<td>7.05</td>
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</tr>
<tr>
<td>Green strength [N/mm²]</td>
<td>15</td>
<td>22</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Sintered density [g/cm³]</td>
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<td>7.00</td>
<td>7.07</td>
<td>7.07</td>
</tr>
<tr>
<td>Tensile strength [N/mm²]</td>
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<td>664</td>
<td>1380</td>
<td>925</td>
</tr>
<tr>
<td>Yield strength [N/mm²]</td>
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<td>488</td>
<td>1100</td>
<td>530</td>
</tr>
<tr>
<td>Elongation [%]</td>
<td>2.5</td>
<td>2.5</td>
<td>1.2</td>
<td>2.5</td>
</tr>
<tr>
<td>Impact energy [joule]</td>
<td>20</td>
<td>15</td>
<td>10</td>
<td>23</td>
</tr>
<tr>
<td>Hardness [HV10]</td>
<td>184</td>
<td>186</td>
<td>362</td>
<td>236</td>
</tr>
<tr>
<td>Dim. change</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green - as sintered [%]</td>
<td>-0.24</td>
<td>+0.12</td>
<td>+0.54</td>
<td>-0.15</td>
</tr>
<tr>
<td>Green - as heat treated [%]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* austenitized at 915 °C, oil-quenched, tempered for 1 h at 175 °C.

9.2.7 Hardenability of Astaloy- and Distaloy-materials

As can be seen from Tables 9.1 and 9.2, the strength properties of Astaloy- and Distaloy-materials can be substantially increased by means of subsequent heat-treatment after sintering. The excellent hardenability of Astaloy- and Distaloy-materials is illustrated by
CCT-diagrams and related microstructures presented at Figs. 9.17 to 9.21. To establish such CCT-diagrams is a rather laborious affair. However, a rough guideline to the hardenability of a sintered iron-based material can be obtained conveniently by determining the microhardness as a function of distance from surface on a polished cross-section of a hardened sample of adequate size, e.g. a tensile-test bar.

Figure 9.17.a. CCT-diagram (top) and amount of phases (bottom) for Distaloy SA + 0.45%C, sintered 30 min at 1120°C in endogas; cooling from 850°C.
Figure 9.17. Microstructures of sintered Distaloy SA + 0.45%C, cooled from 850°C.
Figure 9.18a CCT-diagram (top) and amount of phases (bottom) for Distaloy AE +0.50%C, sintered 30 min at 1120°C in endogas; cooling from 850°C.
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Figure 9.17.b. Microstructures of sintered Distaloy AE + 0.50%C, cooled from 850°C.
Figure 9.19 a. CCT-diagram (top) and amount of phases (bottom) for Distaloy DH-1 + 0.40% C, sintered 30 min at 1120°C in endogas; cooling from 1120°C.
Figure 9.19b. Microstructures of sintered Distaloy DH-1+0.40%C cooled from 1120°C.
Figure 9.20.a. CCT-diagram (top) and amount of phases (bottom) for Distaloy HP-1 + 0.50%C, sintered 30 min at 1120°C in endogas; cooling from 1120°C.
Figure 9.20b. Microstructures of sintered Distaloy HP-1 +0.50%C, cooled from 1120°C.
Figure 9.21.a. CCT-diagram (top) and amount of phases (bottom) for Astaloy Mo + 0.60%C, sintered 30 min at 1120°C in endogas; cooling from 1120°C.
Figure 9.21b. Microstructures of sintered Astaloy Mo + 0.60% C, cooled from 1120°C.
See example at Fig. 9.22 and related microstructures at Fig. 9.23

Figure 9.22. Variation of microstructure and microhardness with distance from surface.

Disiloy AE + 0.5% C. Density: 7.18 g/cm³
Sintering: 30 min at 1120°C in endogas
Hardening: quenched in oil from 850°C
More extensive and detailed information about all materials treated in this chapter are available in the form of specific brochures and electronic data issued by HÖGANÄS AB.
9.3 Applications

As has been demonstrated in the preceding paragraph, a large number of different iron-based materials are available to achieve a great variety of sintered properties and combinations of such properties. Thus, the question is opportune: "Which of these materials is best for what application?" – There is no simple answer.

The final choice in each particular case is normally the result of a chain of laboratory tests, design adaptations, pilot production, functional tests, and commercial considerations. Examples of parts actually produced from materials as described above are presented in Table 9.3 and may serve as a guide. Some of them are also shown on the photograph at Fig. 9.24.

<table>
<thead>
<tr>
<th>Code</th>
<th>Name of sintered structural part</th>
<th>Material</th>
<th>Density g/cm³</th>
<th>Manufacturing procedure (P₁ S₁ P₂ S₂ etc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Belt pulley</td>
<td>Iron-copper-carbon</td>
<td>6.6</td>
<td>P₁ S₁ P₂</td>
</tr>
<tr>
<td>B</td>
<td>Exhaust pipe flange</td>
<td>Iron-Phosphorous</td>
<td>7.0</td>
<td>P₁ S₁</td>
</tr>
<tr>
<td>C</td>
<td>Synchronizing hub</td>
<td>Iron-Nickel-Copper-Molybdenum-Carbon</td>
<td>7.1</td>
<td>P₁ S₁ P₂ M S₂</td>
</tr>
<tr>
<td>D</td>
<td>Lock part</td>
<td>Iron-Nickel-Copper-Molybdenum-Carbon</td>
<td>6.8</td>
<td>P₁ S₁ P₂ M S₂</td>
</tr>
</tbody>
</table>

P₁=Compacting, S₁=Sintering, P₂=Re-pressing, S₂=Re-sintering, M=machining
Convenient assistance in selecting suitable materials for iron-based sintered components can be found in CASIP, a very user-friendly system for Computer-Aided Selection of Iron Powders, developed by Höganäs AB, and running under "MS Windows 95/3.1".

Figure 9.24. Collection of structural parts made of various sintered iron-based materials, (a) Belt pulley, (b) Exhaust pipe flange, (c) Synchronizing hub, (d) Lock part.
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References

[9.2] G. Bockstiegel, Technical and Economical Possibilities of Powder-Forging, (in German), Proceedings from the 9\textsuperscript{th} Hanover Steel-Forming Assembly (UKH-9), March 17\textsuperscript{th} 1977, pp. 27-42.