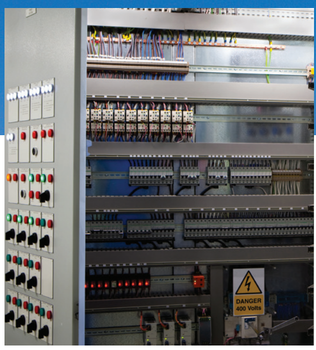
ARMCO® TELAR 57

MAGNETIC IRON

Product Data Bulletin



Relays

Electromagnets

Pole Pieces

ARMCO® TELAR 57 is a soft magnetic material of the High Purity Iron type, particularly favored for D-C relay applications.

It is used in several industrial processes and products, in applications for transportation (aerospace, railway and automotive), magnetic devices (core, pole, yoke and armature magnets), and automation.

Representing ARMCO® products since 1924

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ARMCO® TELAR 57 MAGNETIC IRON

Product Description

ARMCO® Telar 57 is a material variant of ARMCO Pure Iron and was developed to meet the special requirements of the electrical industry. ARMCO Telar 57 is particularly popular in electromagnetic components which have to show high induction levels during magnetization, e.g. relays, electromagnets, pole pieces, and magnet frames.

Based on ARMCO Pure Iron, which is a high-purity steelworks product with a minimum iron content of 99.85 %, natural impurities such as carbon, oxygen, phosphorous and nitrogen have been largely removed. High purity and related 100 % ferritic microstructure are the base for excellent magnetic properties and make ARMCO Telar 57 a preferred soft magnetic material for relay applications.

As a variant of ARMCO Pure Iron, ARMCO Telar 57 contains well-defined additions of following elements:

- Manganese
- Aluminum
- Sulfur

for

- Increased efficiency during decarburization
- Excellent stability against magnetic aging
- Easing machinability in comparison to ARMCO Pure Iron

ARMCO® TELAR 57S

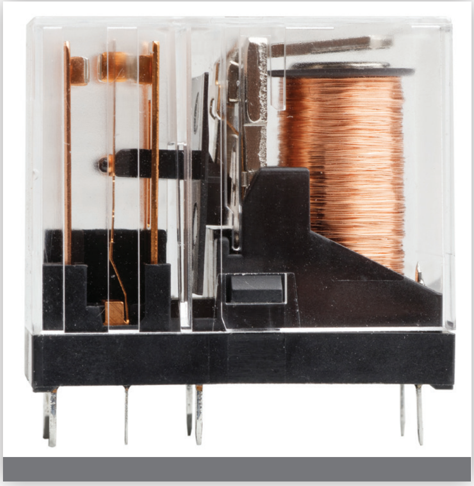
Composition		Analysis %
Carbon	(C)	≤0.02
Manganese	(Mn)	0.35 – 0.5
Phosphorus	(P)	≤0.02
Sulfur	(S)	0.015 – 0.03
Nitrogen	(N)	≤0.005
Copper	(Cu)	≤0.07
Silicon	(Si)	≤0.08
Aluminum	(Al)	0.05 – 0.1

ARMCO Telar 57 is available as version “Telar 57S” for bar stock and for wire. Related version “Telar 57N”, originally available for cold and hot-rolled strip, has been replaced by equivalent ARMCO grades.

ARMCO Telar 57 is characterized by the following important features:

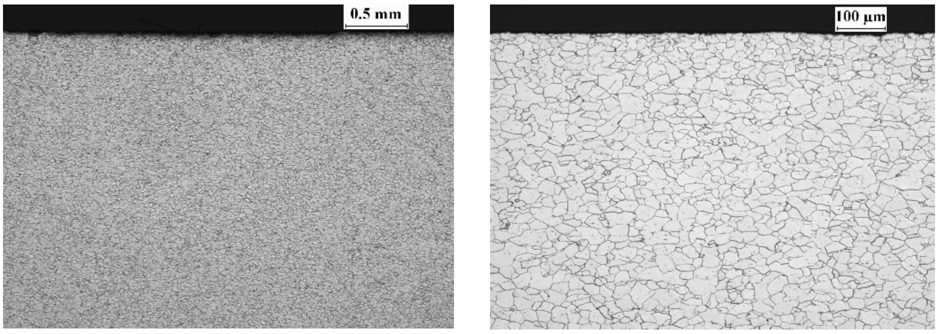
- low coercive force
- high magnetic induction
- excellent aging stability

It achieves the values required in accordance with DIN 17405 for RFe60 to RFe80 grades.



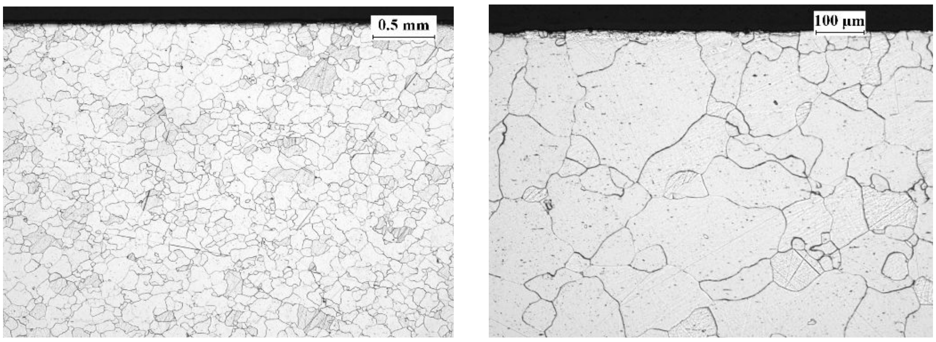
Microstructure

FIGURE 1 – REPRESENTATIVE MICROGRAPHS OF THE GRAIN STRUCTURE OF ARMCO® TELAR 57 BEFORE ANNEAL



Microstructure: 100 % Ferrite. Selected samples (dia. 8 mm cold drawn) in their as-received state show a relatively homogenous grain size, roughly around 50 µm, with no obvious anisotropy.

FIGURE 2 – REPRESENTATIVE MICROGRAPHS OF THE GRAIN STRUCTURE OF ARMCO® TELAR 57 AFTER MAGNETIC ANNEAL



Microstructure: 100 % Ferrite. The samples (dia. 8 mm cold drawn) show an increase in grain size upon magnetic anneal with large grains around 200 to 300 µm.

Physical Properties

TABLE 1 – TYPICAL PHYSICAL PROPERTIES OF HIGH PURITY IRON

Density, g/cm³ (lbs/in³)	7.86 (0.284)
Melting Point, °C (°F)	1532 (2790)
Specific Heat, J/kg/°C (BTU/lbs/°F)	450 (0.107)
Thermal Conductivity, W/m°C BTU/(hr°F•ft²/in.) 20 °C (68 °F)	73.2 (508)
Coefficient of Thermal Expansion, µm/m/°C (µin/in.°F) 20 – 399 °C (68 – 750 °F)	13.7 (7.6)

Mechanical Properties

ARMCO® Telar 57, which is a variant of ARMCO Pure Iron, must be regarded as an unalloyed product and as such is not designed to achieve specific mechanical properties. In particular, the very low carbon content lowers the mechanical properties compared to steels. Moreover, mechanical properties vary according to form, diameter and processing treatments. However, average values are given below for information only and, as such, shall not be used for design without testing. These values are given for a material when it has been annealed at moderate temperatures, namely per magnetic anneal (see the section titled "Background Principles for Heat Treating and Annealing", page 10). A stress relieving heat treatment helps to prevent mechanical aging and stabilizes hardness.

Table 2 gives sample mechanical properties of ARMCO Telar 57 before it is annealed.

TABLE 2 – MECHANICAL PROPERTIES BEFORE ANNEALING

Mechanical properties at room temperature (20 °C, 68 °F) – ARMCO Telar 57 samples before magnetic anneal. Mean values referring to a set of 5 samples are given.

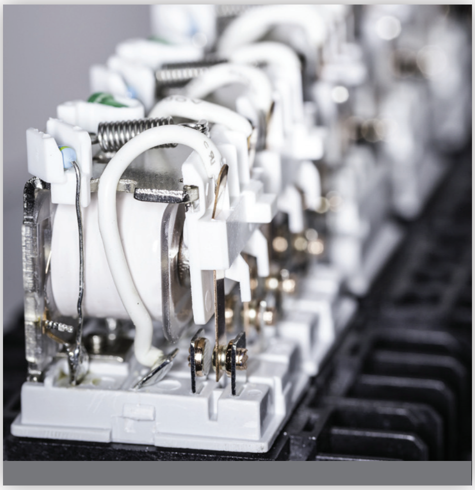
UTS, MPa (ksi)	0.2% YS, MPa (ksi)	Elongation %
384 (56)	360 (27)	19

When ARMCO Telar 57 is annealed to give high permeability at low and moderate inductions and low hysteresis loss, the mechanical properties will change as shown in Table 3.

TABLE 3 – MECHANICAL PROPERTIES AFTER ANNEALING

Mechanical properties at room temperature (20 °C, 68 °F) – ARMCO Telar 57 samples after magnetic anneal. Mean values referring to a set of 5 samples are given.

UTS, MPa (ksi)	0.2% YS, MPa (ksi)	Elongation %
262 (38)	74 (11)	47



Magnetic Properties

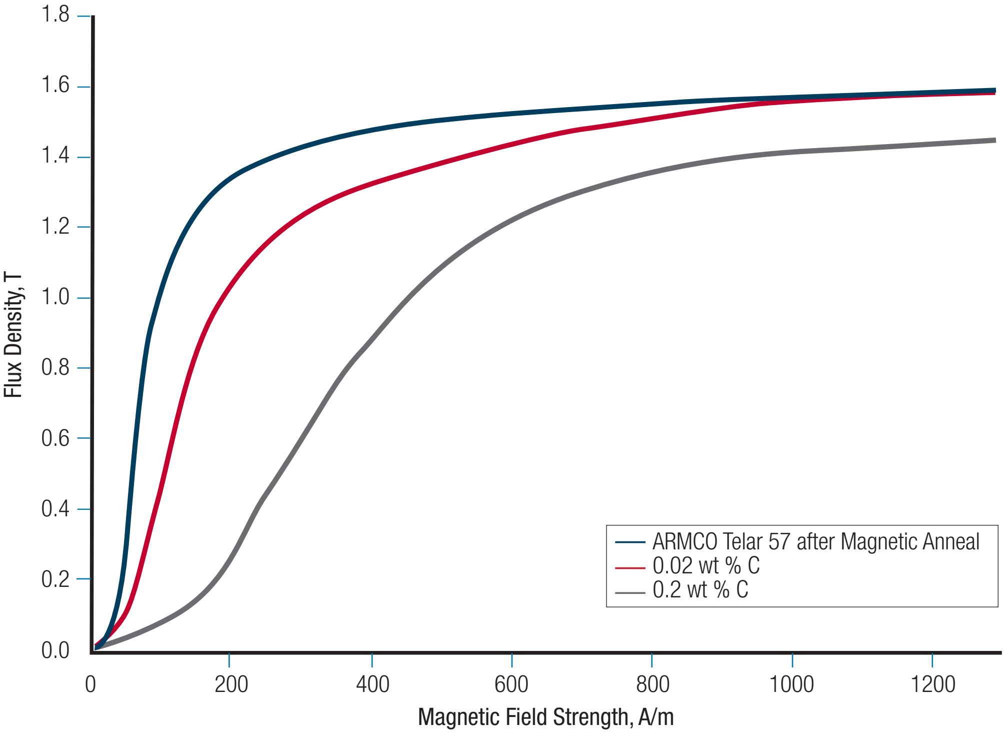
The magnetic product data for ARMCO® Telar 57 presented in this document have been acquired and evaluated for the diameter range 4 – 12 mm, which refers to cold drawn condition.

ARMCO® TELAR 57 VS. LOW CARBON STEEL

To ensure good magnetic properties, such as low coercivity and high permeability, the most important parameter is the carbon content which must be kept very low.

Other residuals may be detrimental to ferromagnetic properties and should be reduced to very low levels except for a few well-defined additions of specific elements for improved machinability and magnetic aging behavior. ARMCO Telar 57, thanks to its very low content of carbon and other residuals, has better magnetic properties than low carbon steel.

FIGURE 3 – EFFECT OF CARBON CONTENT ON THE BH CURVE OF IRON AT LOW INDUCTIONS



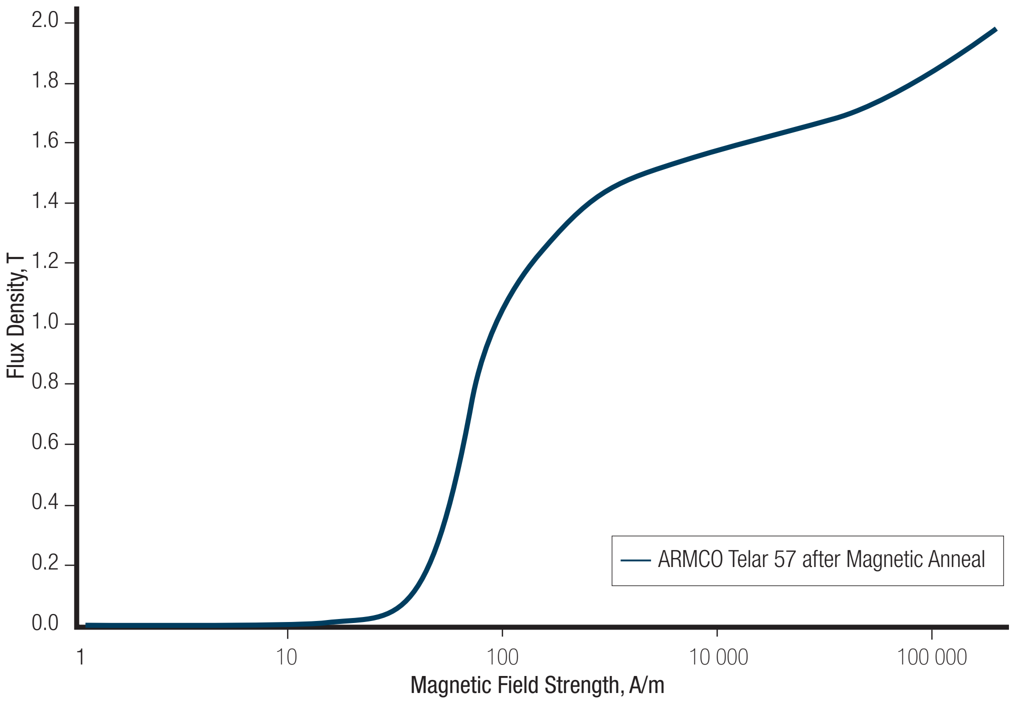
Magnetic Properties

LOW AND MODERATE INDUCTIONS

Some D-C applications operate at medium or low inductions where the metal must magnetize and demagnetize with ease. At these inductions, the chemical composition of the metal determines the level of magnetic quality which is possible.

The grain size and the stress in the finished part determine the degree of quality which is actually attained. When properly annealed, ARMCO Telar 57 meets magnetic quality requirements at these inductions. Annealing temperatures are chosen based off prior processing and required final properties and should result in substantial grain growth and increase in permeability.

FIGURE 4 – REPRESENTATIVE LOW AND MEDIUM INDUCTION VALUES FOR ANNEALED ARMCO® TELAR 57

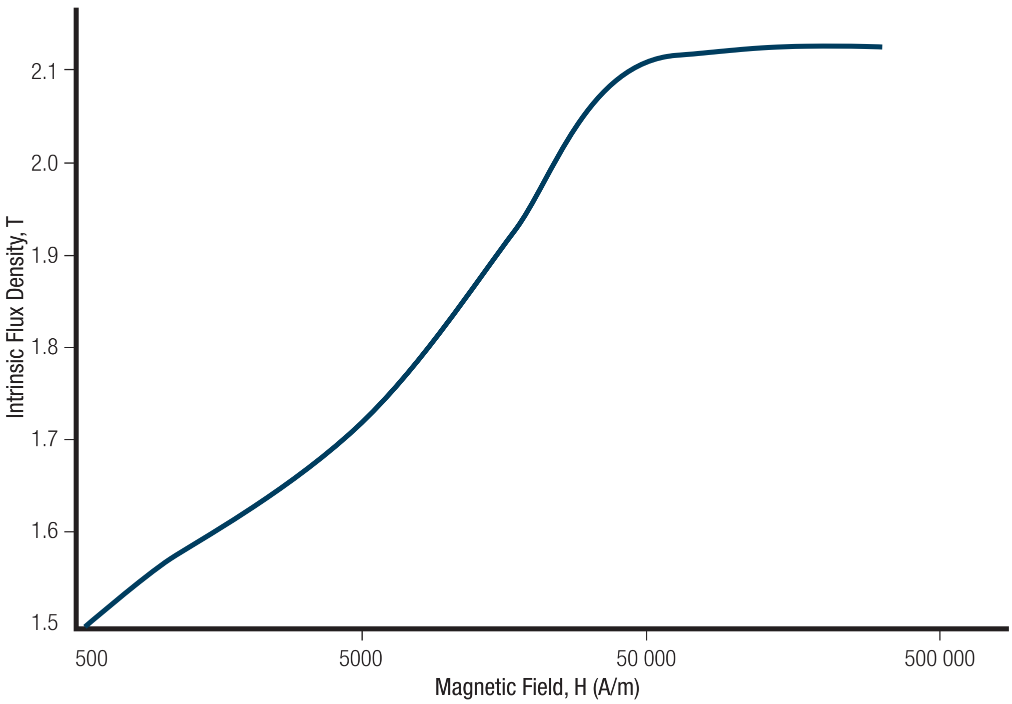


Magnetic Properties

HIGH INDUCTIONS

For many applications it is desirable to produce the highest possible flux density with a minimum of ampere-turns. ARMCO® Telar 57 is especially suited for these uses because of its high degree of purity and related high percentage of iron. High induction values obtained with ARMCO Telar 57, over the range of high magnetic field strength where magnetic saturation is being approached, are shown in Figure 5. Over this range, the permeability (or B/H ratio) is high when compared with the permeability of nearly all magnetic materials. ARMCO Telar 57 and related ARMCO Pure Iron have a maximum intrinsic induction ($B-\mu_0 H$), or a saturation induction value of 2.15 T (21.5 kG).

FIGURE 5 – HIGH INDUCTION MAGNETIZATION CURVE FOR ARMCO® TELAR 57



Magnetic Properties

PERMEABILITY

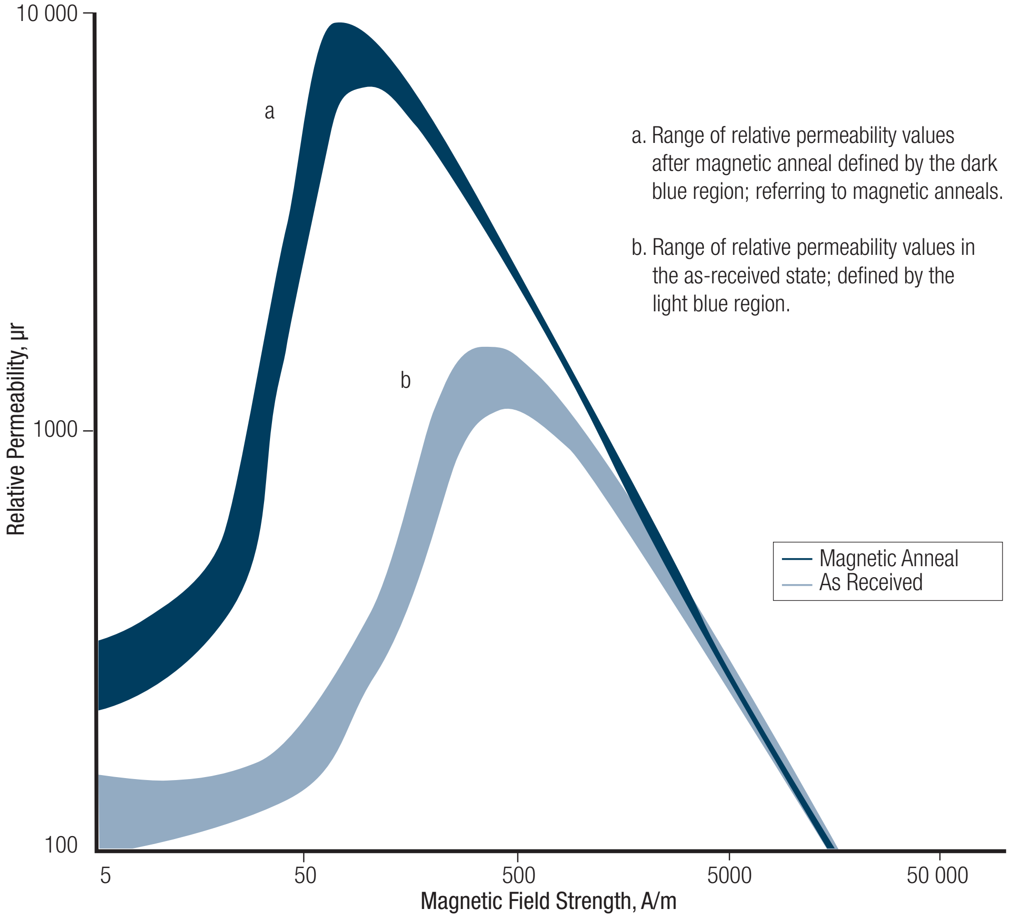
Figure 6 shows a plot of the relative permeability, or the $B/(\mu_0 H)$ ratio, over a wide range of magnetic field strengths. The colored regions between the curves at low and medium inductions are representative of results before and after magnetic anneal.

Round bars with diameters of 4 mm, which originate from drawing with a higher degree of cold work are excluded from Figure 6 as these products are not regarded as representative of the material. The general impact of moderate cold working is shown in Figure 8, and detailed data for the diameter 4 mm item are included in Table 4 and Figure 9.

Laboratory tests on magnetic materials are usually made with a closed magnetic circuit in which there is no air gap, or one in which the air gap is either compensated for or held to a minimum. As a rule, however, magnetic core circuits include an air gap. This results in apparent properties that are somewhat different from those of the magnetic material. For this reason, it is recommended that the performance of ARMCO Telar 57 be judged from tests made under the actual conditions in which it will be used.

See following sections for details on anneal procedures: “Background Principles For Heat Treating and Annealing”, and “Recommendations for Heat Treating and Annealing”.

FIGURE 6 – RELATIVE PERMEABILITY OF ARMCO® TELAR 57 OVER A RANGE OF MAGNETIZING FIELD STRENGTH



Magnetic Properties

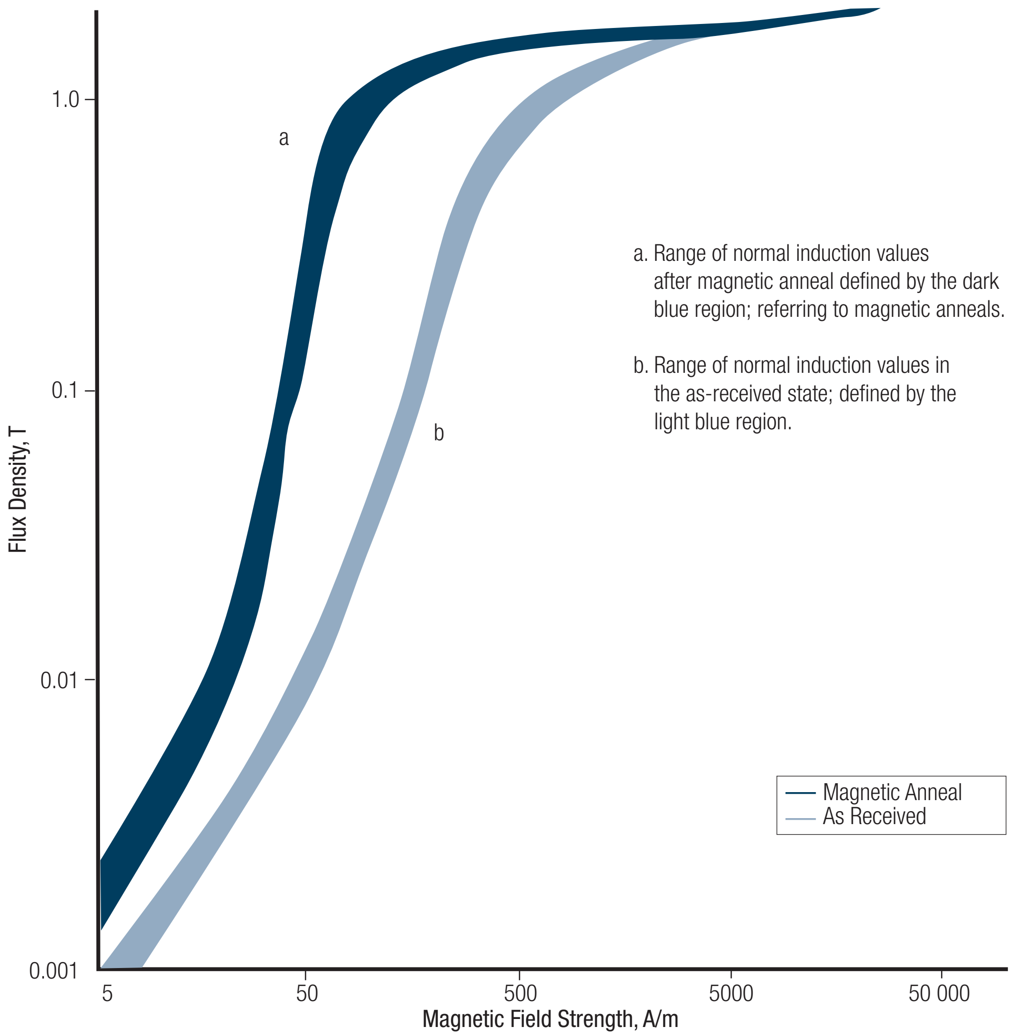
RANGE OF VALUES

The variety of gages, shapes and sizes in which ARMCO® Telar 57 is available results in corresponding differences in processing. For these reasons the permeability to be expected can best be represented by a range of values, rather than a single curve. The magnetization curves obtained on representative samples of ARMCO Telar 57 given a magnetic anneal would lie mostly within the dark blue zone of Figure 7. Similarly to the ranges of relative permeability shown in Figure 6 samples with very small diameter or originating from strong cold working are not included in Figure 7 as they are not representative of the material.

The location of a curve within a band or zone would be determined by such factors as annealing temperature, time of soaking period, type and condition of the annealing atmosphere, and previous processing history. For optimum magnetic properties and simplicity of annealing, a temperature of 820 °C (1508 °F) is generally recommended.

See following sections for details on anneal procedures: "Background Principles For Heat Treating and Annealing", and "Recommendations for Heat Treating and Annealing".

FIGURE 7 – MEDIUM AND LOW INDUCTION VALUES – ANNEALED ARMCO® TELAR 57



Magnetic Properties

EFFECT OF STRESSES ON MAGNETIC PROPERTIES

All mechanical operations on iron and steel – such as rolling, drawing, forging, bending, forming and machining – create internal stresses. This is especially true of cold-working operations. It applies to a lesser degree as the working temperature is raised. Stresses which result from mechanical work are harmful to the magnetic properties.

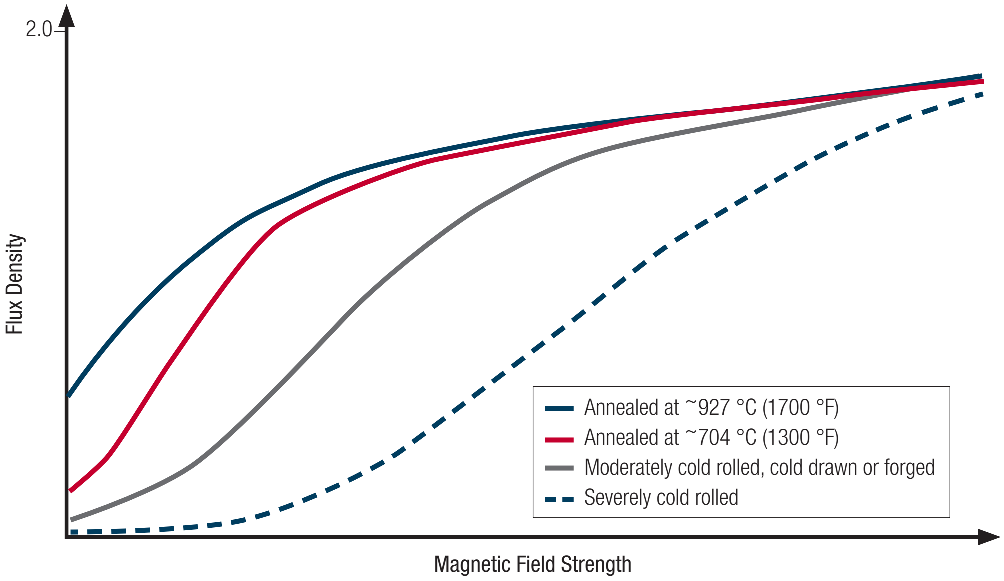
Figure 8 illustrates the qualitative effect of cold work on the shape of the magnetization curve. At low and moderate inductions, permeability is lowered sharply by moderate cold rolling, drawing or forging. More severe working causes a further decrease in permeability where the exact behavior will depend on a combination of factors such as chemistry, processing, annealing parameters, and atmosphere, etc.

MAGNETIC PROPERTIES AFFECTED BY SEVERE COLD WORKING

High-induction permeability is not adversely affected by cold working normally encountered in the fabrication of finished parts. But severe cold working has its effect even at 1.8 T. The general effect of mechanical and machining stresses on the hysteresis loop is to increase the coercive force and the hysteresis loss. The iron may be annealed after mechanical working. However, severely cold worked material may not achieve comparable magnetic properties as occur for less worked material.

No attempt has been made to show the effect of light mechanical working, since this would be influenced by both the type and the degree of working. On small cross sections, even light mechanical stresses may affect the operation of the part. On heavy sections, the effect of a light machining operation is likely to be negligible.

FIGURE 8 – EFFECT OF STRESS ON THE MAGNETIZATION CURVE OF HIGH PURITY IRON



Qualitative effect of cold work on the shape of the magnetization curve of high purity iron. The diagram is intended to show a qualitative trend for unalloyed iron for magnetic applications. Detailed quantitative information on the magnetic field is represented in other parts of this document.

Background Principles for Heat Treating and Annealing

ANNEALING

Since practically all applications for ARMCO® Telar 57 require mechanical work during fabrication, it is strongly recommended that finished parts be annealed for best magnetic performance. The function of the usual, commercial anneals of ARMCO Telar 57 is to restore the magnetic properties without the benefit of any further purification.

The following are general rules, precautions, and suggestions for the commercial annealing of magnetic parts. The cycle to be used depends on a number of factors:

1) The magnetic application (induction range).

2) Annealing equipment available (size and type of furnace).

3) Mass, weight, and thickness of charge.

The material may be heated at a relatively fast rate, but through the high temperature range it should be cooled slowly to avoid even slight distortion and the accompanying strains. The normal heating and cooling rates for batch furnaces are usually quite satisfactory, except that the cooling rate at high temperatures should not be much faster than the heating rate for this same range of temperatures. If the charge is fully protected by a box or cover, it may be removed from the furnace at approximately 316 – 371 °C (600 – 700 °F). The temperature at which the charge itself may be exposed to the air depends upon the amount of surface oxidation which can be tolerated. The material should be soaked at a maximum temperature just long enough to insure a uniform temperature throughout. This may vary from one to several hours. To obtain consistently good results, the fabricator is advised to arrive at the best annealing cycle by experimentation. The recommendations given here are offered only as a guide.

ATMOSPHERE

It is important that ARMCO Telar 57 does not become contaminated by the annealing atmosphere. Even as little an increase as 0.01 % in carbon content is harmful to the magnetic properties. Excessive oxidation is injurious to the magnetic qualities and sometimes produces brittleness. An ideal atmosphere is one which is neither oxidizing nor carburizing. Best atmospheres are reducing atmospheres such as moist hydrogen or 100 % dry hydrogen. A common annealing atmosphere is 20 % wet hydrogen mixed with 80 % dry hydrogen by volume at a dew point of 13 – 18 °C (55 – 65 °F). Dissociated ammonia is referred to as an alternative option for reducing atmosphere. If a reducing atmosphere cannot be achieved, an inert atmosphere should be used. Inert atmospheres include dry nitrogen, argon, or a vacuum.

With any of the annealing methods, care should be taken to avoid the inclusion of any carbonaceous materials, such as uncombusted natural gas, oil, or high-carbon alloys. This is especially important at the higher temperatures. Under certain annealing conditions, there may be some tendency toward brittleness of the iron. This can be prevented by annealing either in a sealed package, a box sealed by welding, or in a combusted gas atmosphere as described above. Either of these anneals can be used to remove brittleness caused by a previous anneal.

Recommendations for Heat Treating and Annealing

AK Steel Research provides the following heat treatment guidelines for ARMCO® Telar 57. These recommendations are considered to be conservative and may be optimized as required to account for factors such as part geometry, the efficiency of the furnace, available annealing atmospheres, and time restraints. The temperatures listed in the procedures below are charge temperatures; the furnace set points should be selected to ensure the product reaches the desired heat treatment temperature. Additionally, when designing a furnace cycle, it is critical to ensure that the heating and cooling rates are sufficiently slow to provide uniform thermal gradients throughout the charge. The magnetic properties of iron are highly dependent on the final strain-state of the metal matrix and non-uniform thermal gradients may result in development of internal stresses.

MAGNETIC ANNEAL (RECOMMENDED)

The recommended temperature initiates nucleation and growth of strain-free grains. This treatment typically follows the last mechanical processing stage.

Heating:	2 – 4 °C (4 – 7 °F) per min
Hold Temperature:	820 °C (± 20 °C) / 1508 °F (± 36 °F)
Hold Time:	A minimum of 60 minutes with an additional 15 minutes per each 5 mm (0.2 in.) thickness over 25 mm (1.0 in.)
Cooling:	2 – 4 °C (4 – 7 °F) per minute until the change temperature is below 550 – 600 °C (932 – 1112 °F).

The parts should remain in a protected atmosphere until the temperature of the parts is below 300 °C (572 °F).

OTHER ANNEALS

Stress-Relief Anneal (SRA) – A low temperature anneal used to minimize adverse effects of production and machining processes. Minimal change to the grain structure is observed. Recommended guidelines are similar to a magnetic anneal, but with a maximum of 700 °C (± 20 °C) / 1292 °F (± 36 °F) for hold temperature.

Severely cold worked material may benefit from special anneals for which a higher temperature or a longer hold time is carefully applied as compared to a usual magnetic anneal. Caution is advised at elevated temperatures to take into consideration increased tendency to stick and decreased mechanical strength.

Decarburization – Special anneal to improve magnetic properties by reducing the carbon content. See Special Anneals on the following page.

Recommendations for Heat Treating and Annealing

SPECIAL ANNEALS

Purification annealing at temperatures above that needed for stress relieving can provide further improvement in the magnetic properties of ARMCO® Telar 57. This purification is usually accomplished by special annealing for extended periods in a vacuum or in a carefully controlled atmosphere of hydrogen.

TABLE 4 – REPRESENTATIVE MAGNETIC PROPERTIES – AS RECEIVED AND AFTER MAGNETIC ANNEAL

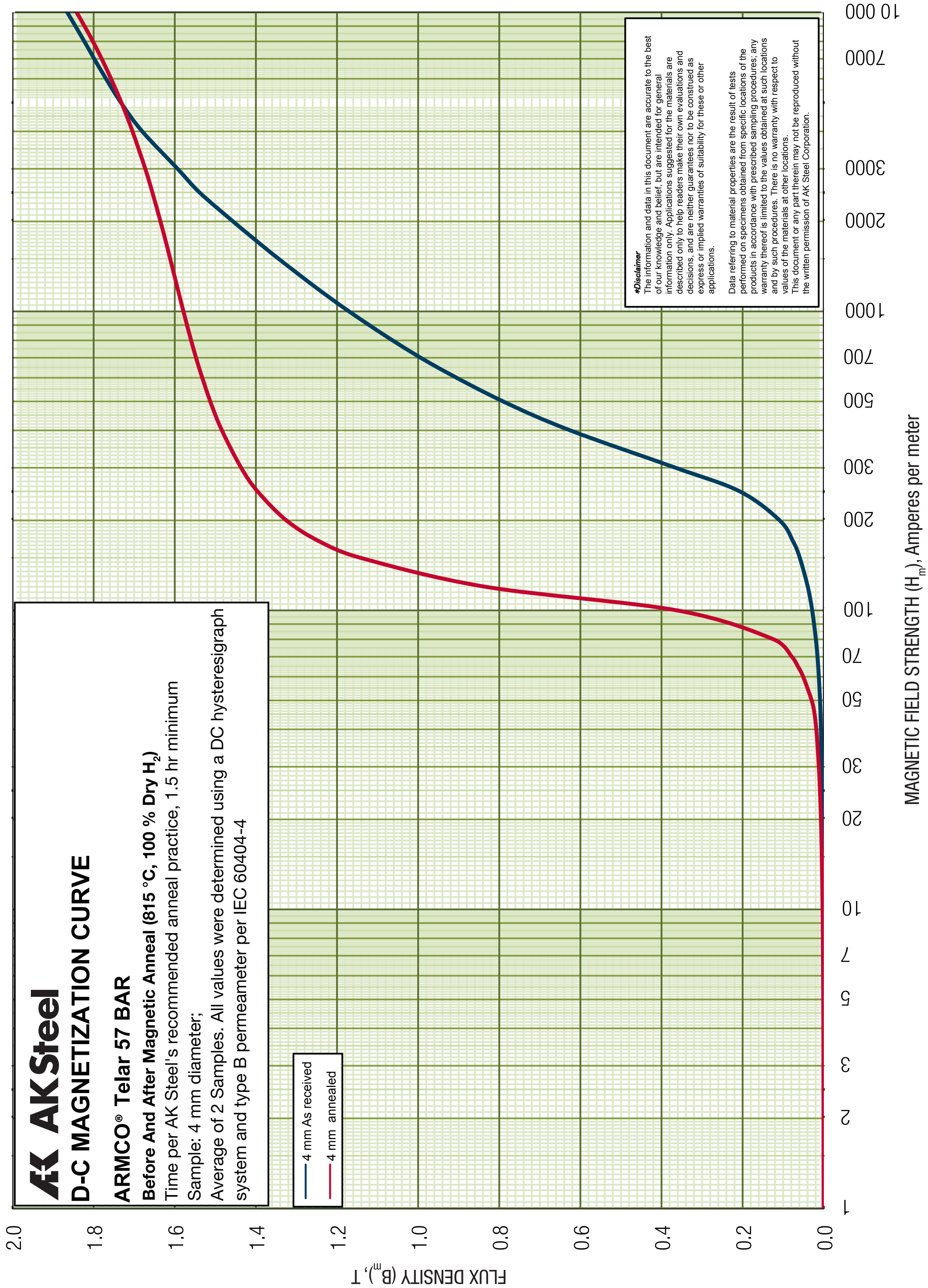
ARMCO Telar 57	As Received		Magnetic Anneal		RFe80 acc. to DIN 17405	
	SI	U.S. Customary	SI	U.S. Customary	SI	U.S. Customary
Maximum relative permeability, μ_{max}	1000 – 2500		5000 – 10 000		–	–
Coercive force, H_c at H = 55 kA/m (690 Oe)	200 – 350 A/m	2.5 – 4.4 Oe	50 – 70 A/m*	0.6 – 0.9 Oe	max. 80 A/m	max. 1 Oe
B at H = 1.2 kA/m (15 Oe)	1.2 – 1.36 T	12 – 13.6 kG	1.55 – 1.6 T	15.5 – 16 kG	min. 1.2 T	min. 12 kG
B at H = 24 kA/m (300 Oe)	2.02 – 2.05 T	20.2 – 20.5 kG	2.02 – 2.05 T	20.2 – 20.5 kG	–	–

**The H_c range 50 – 70 A/m typically applies to material without strong cold working. If severely cold worked material is taken into account the range in which the coercive force most likely lies extends to 50 – 120 A/m (0.6 – 1.5 Oe).*

ARMCO® TELAR 57 MAGNETIC IRON

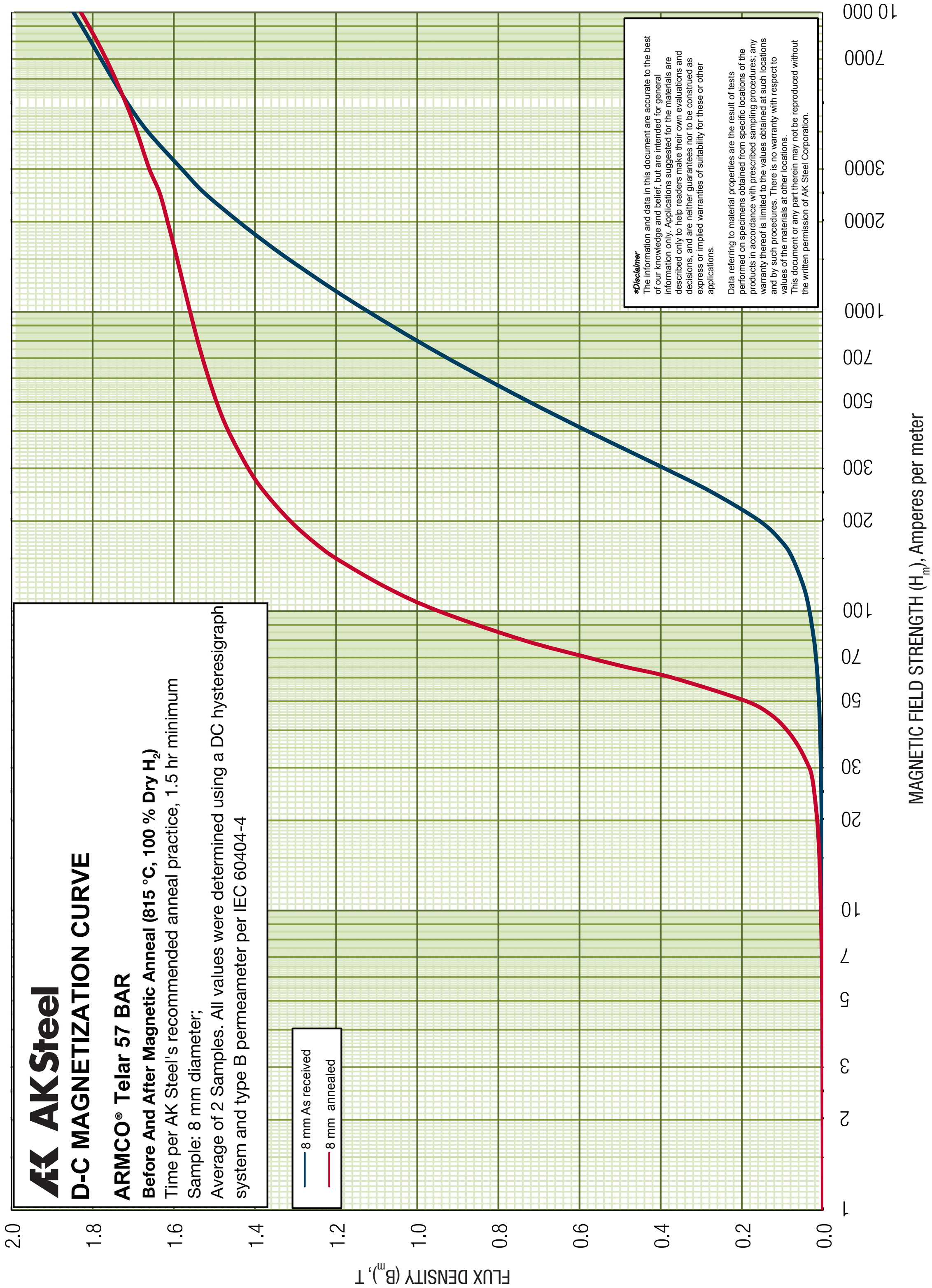
D-C Magnetization Curves

FIGURE 9 – ARMCO® TELAR 57 COLD DRAWN BAR DIAMETER 4 MM



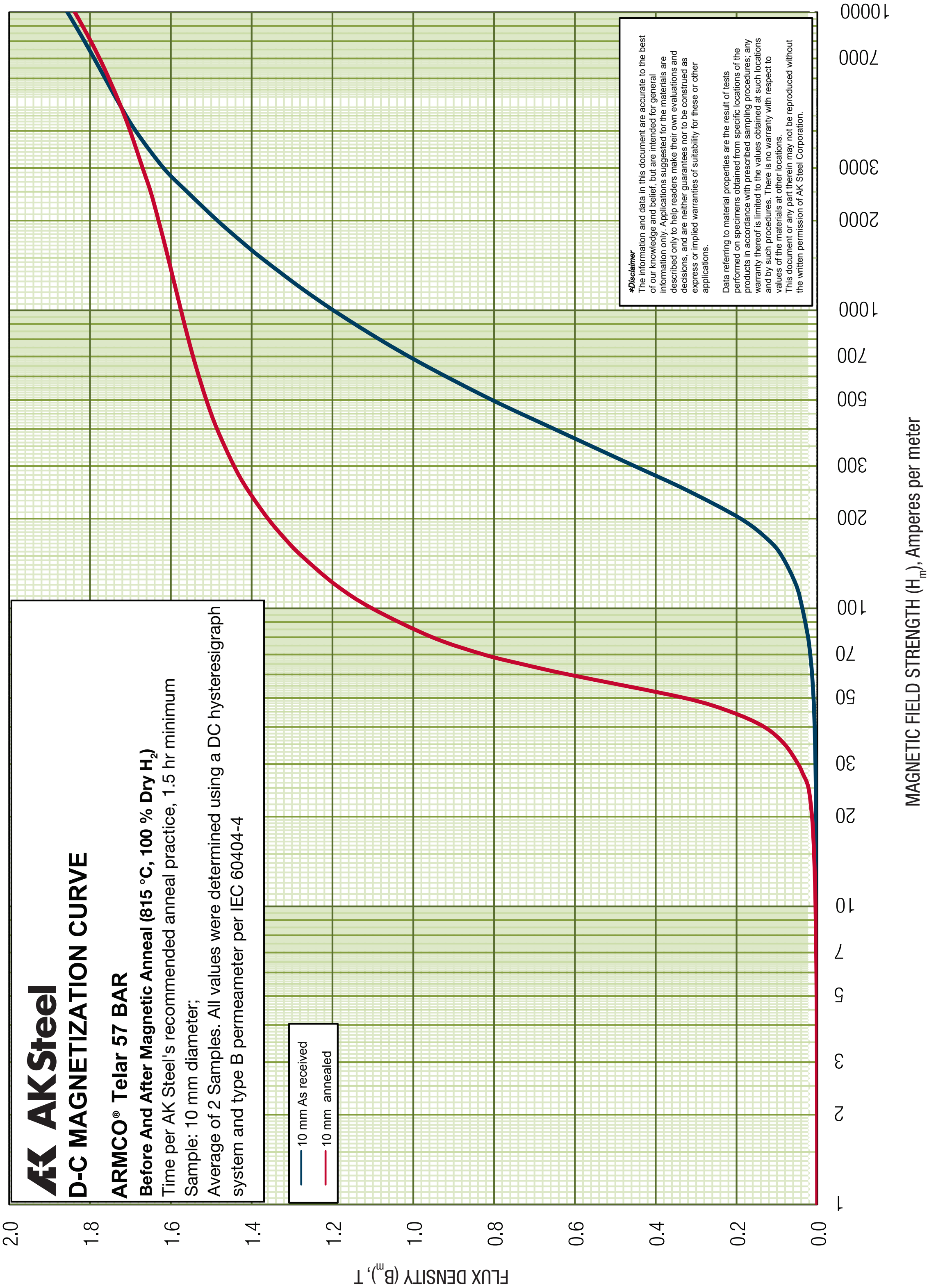
D-C Magnetization Curves

FIGURE 10 – ARMCO® TELAR 57 COLD DRAWN BAR DIAMETER 8 MM



D-C Magnetization Curves

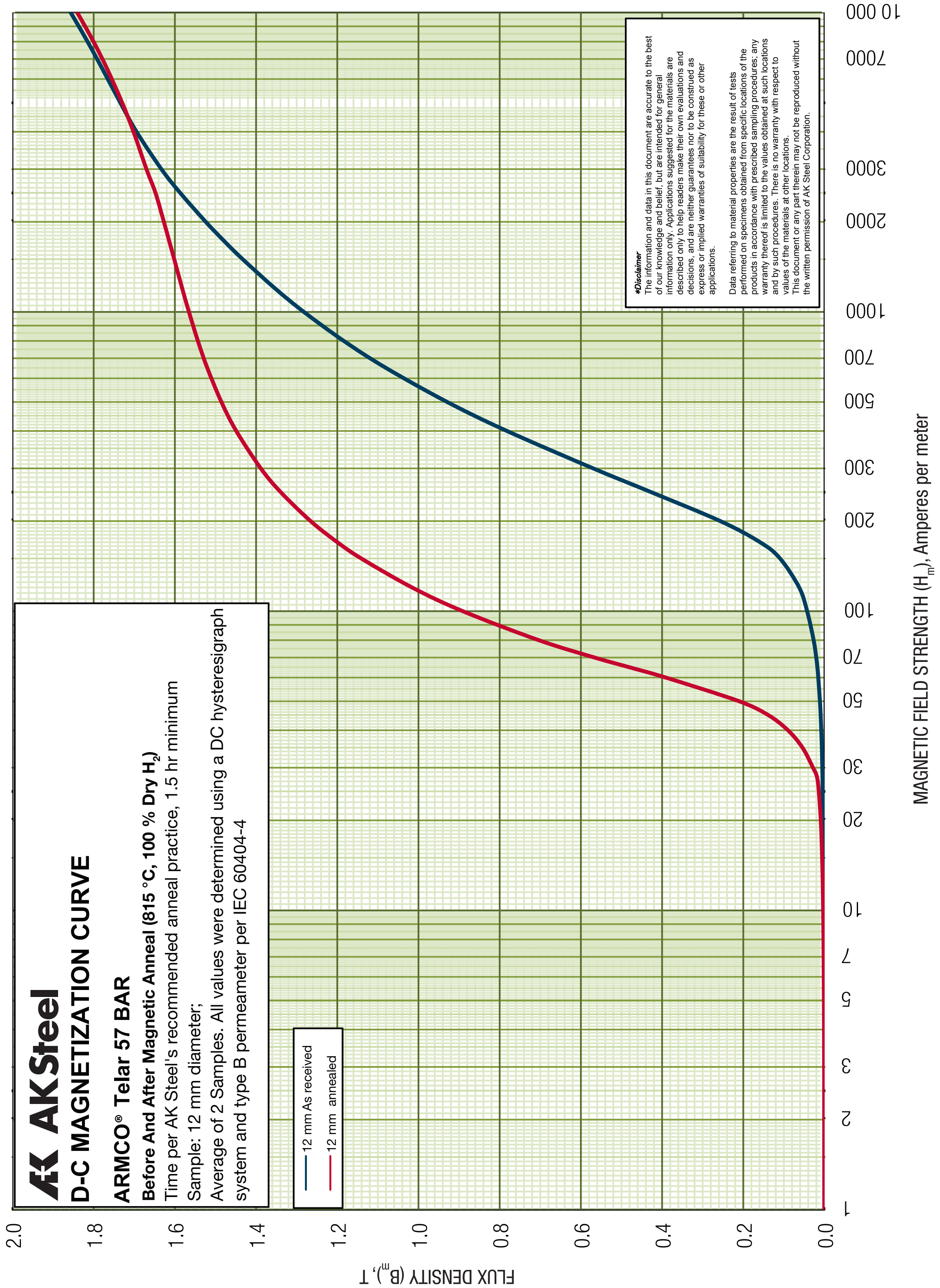
FIGURE 11 – ARMCO® TELAR 57 COLD DRAWN BAR DIAMETER 10 MM



ARMCO® TELAR 57 MAGNETIC IRON

D-C Magnetization Curves

FIGURE 12 – ARMCO® TELAR 57 COLD DRAWN BAR DIAMETER 12 MM



Magnetic Aging

While aging in higher purity grades of unalloyed iron should be minimal, it is characteristic of commercial irons that a slow change may take place in the magnetic properties at low and medium inductions. This is especially true of material that has higher carbon content. This change in magnetic properties, commonly termed "magnetic aging", is caused by a gradual precipitation of carbon, oxygen, or nitrogen compounds from solid solution. As aging progresses the magnetic permeability decreases and the coercive force, residual induction and hysteresis loss increase. At room temperatures, it may take years for the change in magnetic properties to be significant and may not change at all. At higher temperatures, the rate of change increases. The maximum rate of change, as well as the maximum total change, occurs between 100 – 150 °C (212 – 302 °F). Above 177 °C (350 °F) these changes are less marked.

Aging can often be greatly reduced using a magnetic anneal (see the section titled "Recommendations for Heat Treating and Annealing") within a hydrogen-bearing atmosphere. Annealing under these conditions will reduce the change in magnetic properties from aging by lowering the carbon, oxygen, and nitrogen content of the iron. If stabilized magnetic properties are a primary requirement, it is recommended that a baking treatment at a lower temperature, usually between 177 – 260 °C (350 – 500 °F), is performed after magnetic annealing. This will result in stable magnetic properties at a somewhat lower level than freshly annealed.

Experiments for various product conditions and gages have shown that ARMCO® Telar 57 has excellent aging stability. Irrespective of the item dimensions the increase in the coercive force as determined per norm DIN 17405 is below 3 %.

Excellent resistance against magnetic aging in combination with low coercive force and high magnetic permeability is a unique feature related to ARMCO Telar 57. For advanced D-C electromagnetic applications with highest requirements for long-term stability under various ambient conditions it gives the preference to ARMCO Telar 57 over ARMCO Pure Iron.

Processing

COLD WORKING

The outstanding purity of ARMCO® Telar 57 provides a high level of softness and cold forming capability (reduction in area of approximately 90 %). Non-cutting cold forming processes (especially drawing, deep-drawing, pressing, and cold forging) therefore produce only minor compressive strain which enable high forming levels. Under controlled forming, the tensile strength can increase to double the initial value.

The excellent cold-working qualities of ARMCO Telar 57 are based on its density, ductility, and uniformity, which contribute to successful bending, drawing, and stamping operations. Cold working, however, is more injurious to the magnetic qualities than hot working, and annealing is usually necessary to restore its magnetic properties.

MACHINING

TURNING

Both high-speed steel and hard metal tools can be used for machining ARMCO Telar 57. Sharply ground tools and carefully selected cutting data are particularly important, since in the case of incorrect selection, ARMCO Telar 57 tends to smearing. The most rational production for coarse turning is achieved with a slow feed and a deep cut. Where the best surface quality and dimensional accuracy are required in fine turning, the feed should not exceed 0.1 mm. With correctly selected cutting data, surfaces that have not been machined will be matte and the turned surfaces will have a smooth, glossy appearance. Adequate cooling and lubrication are also essential in order to preserve the tool and the workpiece. It is recommended to use a mineral oil containing 1 – 1.5 % sulfur and 5 % grease.

MILLING

In order to obtain a fine surface, a cylindrical milling cutter with a pitch angle of 45°– 52° is recommended. The radial cutting angle should be 30°. At cutting speeds of 25 – 45 m/min., a feed of 19 – 32 mm/min. should be selected. The use of side milling cutters requires a radial cutting angle of 10°. A clean, swarf gap shape must be ensured on the tool. For cooling and lubrication, the same recommendations apply as for turning.

THREAD CUTTING

Normal cutting tools can be used for the production of individual threads. As soon as the required number of threads increases however, non-cutting thread production provides more economical results. This can be used for the production of both internal and external threads. This increases the strength values, reducing the danger of the thread being stripped.

DRILLING

A slightly lower free angle should be selected than for drilling normal steels. The cutting speed is approx. 24 m/min., the feed approximately 0.05 – 0.10 mm/rev.

SAFETY | QUALITY | PRODUCTIVITY | INNOVATION

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Data referring to material properties are the result of tests performed on specimens obtained from specific locations of the products in accordance with prescribed sampling procedures; any warranty thereof is limited to the values obtained at such locations and by such procedures. There is no warranty with respect to values of the materials at other locations.

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