ARMCO Pure Iron

- **Excellent magnetic properties**
- **High chemical and metallurgical purity**
- **Improved resistance against corrosion and oxidation**
- **Good cold forming capability**
- **Ideally suitable for welding**

Developed in 1909 by the **A**merican **R**olling **M**ill **Co**mpany (**ARMCO**), and produced in Germany for the first time in 1927, **ARMCO Pure Iron**, with its history of over a century, is still an important product today because of its flexible application possibilities. Today as before, **ARMCO Pure Iron** is produced to meet the highest quality requirements, and is used in a wide range of applications such as welding rods and fuse wire, as magnetic shielding in the radiography and nuclear spin tomography sector and many other magnetic applications such as pole cores, yokes and armatures.

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The data referring to mechanical properties and chemical analyses are the result of random samples from certain areas and comply with the mandatory procedures. All guarantees relating to these values are restricted to the experimental plants and procedures used. No guarantee is given for material values obtained in other experimental plants.

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ARMCO Pure Iron

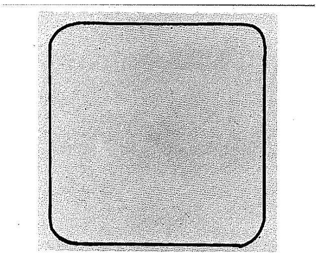
ARMCO Pure Iron is a steelworks product unique in its purity, with an iron content of min. 99.85%, without the addition of alloy elements. All natural impurities have been largely removed.

Developed in 1909 in the USA, **ARMCO Pure Iron** was first produced in Germany in 1927. Even after over three-quarters of a century of technical progress, **ARMCO Pure Iron** is still an important product because of its flexible application possibilities. Today as before, **ARMCO Pure Iron** is produced to meet the highest quality requirements.

ARMCO Pure Iron undergoes pacification after melting in the LD converter by means of vacuum degassing. Following solidification, it therefore has a homogenous composition with regard to the distribution of the accompanying elements, a very low oxygen content and very good slag purity. Due to the low carbon content, the micro-structure consists of pure ferrite.

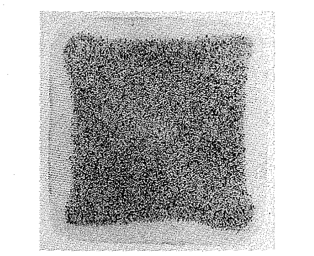
Sulphur Prints (after Baumann)

Figure 1
ARMCO Pure Iron



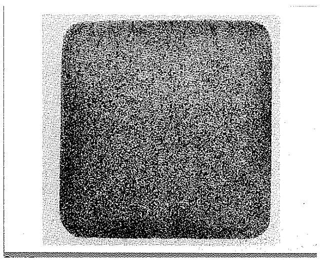
homogenous structure
with very low S-content

Figure 2
unskilled Steel (S 235 JRG 1)



with separation-free edge zone
and separation zone

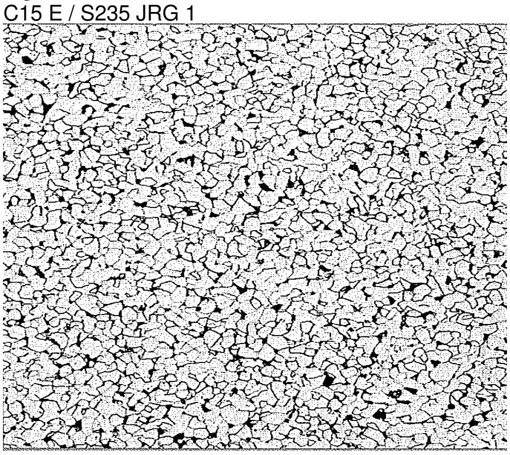
Figure 3
skilled steel (C 15 E)



homogenous structure
with normal S-content

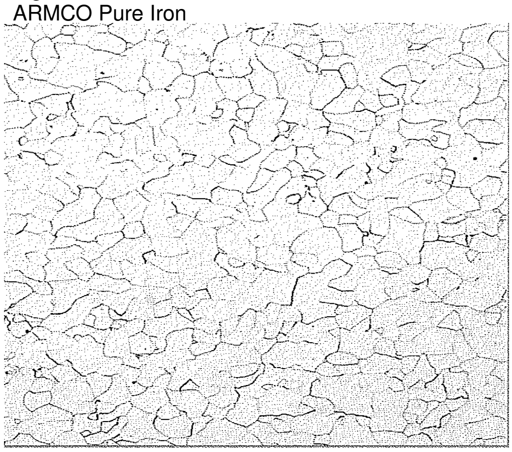
Micro-Structure at 100x enlargement:

Figure 4
C15 E / S235 JRG 1



irregular ferrite-perlite structure

Figure 5
ARMCO Pure Iron



even ferrite structure,

Chemical Composition
Max. Analysis, %

Grade	C	Mn	P	S	N	Cu	Co	Sn
1	0.020	0.200	0.015	0.015	0.007	0.060	-**	0.010
2	0.010	0.100	0.010	0.008	0.006	0.030	-**	0.010
3	0.010	0.080	0.010	0.003	0.005	0.030	-**	0.010
4	0.010	0.060	0.005	0.003	0.005	0.030	0.005	0.005

* no regular production
** not determined

The high purity of **ARMCO Pure Iron** is the major reason for the following special properties:

- excellent magnetic properties
- improved resistance against corrosion and oxidation in comparison to normal steels
- good cold forming capability
- ideally suitable for welding

Applications

ARMCO Pure Iron is used largely as the basic material for (re-)melting of low-carbon, stainless and acid-resistant steels, materials with a high nickel content, magnetic alloys as well as stainless and heat resistant steel castings in induction and vacuum furnaces.

ARMCO Pure Iron is also used in many applications of aviation construction, nuclear technology, the production of magnets (pole cores, yokes and armatures), in automotive construction, as magnetic shielding, as welding rods and fuse wire, as gasket in the chemical and petrochemical industry, power station construction, as anti-corrosion anode and as galvanizing tank including equipment.

Mechanical Properties

	Brinell Hardness (HB)	
ARMCO Pure Iron	**max.**	**typical**
Cold-rolled strip / sheet	105	90
Hot-rolled strip / plate	105	90
Quarto plate	100	90
Round bar	110	95

The above values must be agreed in individual cases and on placement of the order!

Electrical and Magnetic Properties

Characteristics	Typical Values
Initial Permeability	300 – 500
Permeability	3500 - 6000
Coercive Force	60 – 120 A/m
Saturation Induction	2.15 T
Density at 20 °C	7.86 kg/dm³
Melting Point	1536 °C
Linear Expansion Coefficient Temperature Range 0 – 100 °C	$12x10^{-6}$ 1/°C
Modulus of Elasticity	207 kN/mm²

The purer a metal is, the better it conducts electrical current. Materials of the greatest possible purity are therefore required for current-carrying components. Even fractions of a percent of C, Si, P, S, Mn and Cu, which are found in normal types of steel, impact the electrical conductivity, which corresponds to the reciprocal value of the specific resistance. For **ARMCO Pure Iron,** the specific electrical resistance at 20 °C is approx. 10.7 micro-ohms/cm.

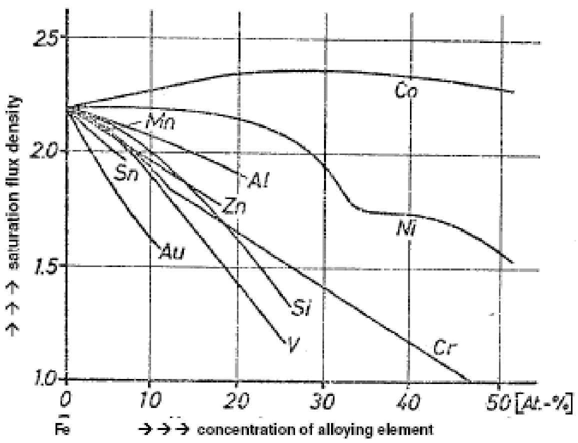
In addition to its electrical properties, the magnetic properties of **ARMCO Pure Iron** constitute other major advantages:

- high magnetic saturation
- low coercive field strength and remanence
- high permeability, from in the medium induction ranges

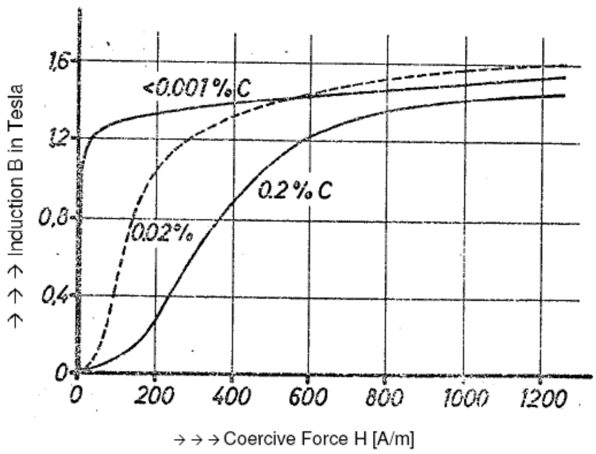
As shown in the following graphics, the alloy elements of iron, with the exception of cobalt, impair the magnetic properties (saturation induction). Carbon exerts a crucial effect.

Magnetic properties in relation to the other elements contained in the iron.

Saturation curve of binary iron alloys



Induction curves of low-carbon steels



The good basic magnetic properties of **ARMCO Pure Iron** resulting from its purity can be further optimised by specific processing. This requires the following forming / heat treatments:

1. normalising or recrystalising annealing after hot or cold forming.
2. subsequent cold forming of approx. 6%
3. magnetic annealing to DIN 17405 (4h, 820 °C in a decarbonising atmosphere, slow cooling). Such processing enables a coercive field strength of at least 20A/m (see page 12).

With regard to the ageing resistance, the following extremely low values apply for the increase in the coercive field strength, in relation to ageing up to 100 °C

after 100 hours = 0.02 Oersted

after 300 hours = 0.04 Oersted.

Note!!! All cold processing causes tensions in the structure, and a consequent deterioration of the magnetic properties. In order to regain the optimum values, the finished parts must undergo final annealing.

Coercive Force

Sample – No.	Condition / Treatment	H_c A / m	B_{25} T	B_{50} T	B_{100} T	B_{200} T	B_{300} T	$B_{saturates}$ T
1	condition of delivery	109,8	1,62	1,73	1,84	1,97	2,04	
2		100,3	1,61	1,73	1,84	1,97	2,04	
3	magnetically annealed	66,1	1,67	1,74	1,84	1,97	2,06	
4		66,1	1,67	1,74	1,84	1,97	2,06	
5	normalised	74,4	1,65	1,73	1,83	1,96	2,05	
6		66,1	1,65	1,73	1,83	1,96	2,05	2,13
7	normalised and magnetically annealed	56,9	1,66	1,73	1,83	1,97	2,05	
8		56,1	1,65	1,72	1,82	1,96	2,05	
9	normalised and 6 % deformed	206,9	1,56	1,70	1,82	1,96	2,05	
10		199,0	1,56	1,70	1,82	1,96	2,05	
11	normalised, 6 % deformed, magnetically annealed	34,2	1,65	1,74	1,85	1,98	2,06	
12		40,6	1,64	1,72	1,82	1,96	2,05	
13	normalised	52,5	1,65	1,72	1,83	1,96	2,05	2,13
14		52,1	1,65	1,72	1,83	1,96	2,05	
15	normalised and magnetically annealed	43,4	1,66	1,73	1,83	1,96	2,05	
16		42,6	1,66	1,73	1,83	1,96	2,05	
17	normalised and 6 % deformed	183,0	1,58	1,70	1,81	1,95	2,04	
18		179,1	1,58	1,70	1,82	1,96	2,04	
19	normalised, 6 % deformed, magnetically annealed	20,7	1,63	1,70	1,81	1,95	2,04	
20		20,7	1,61	1,69	1,80	1,95	2,04	

Material Test: V42/80, Thyssen Stahl AG, 14.2.1991
Item 1 – 12: HR Wire
Item 13 – 20: Heavy Plate

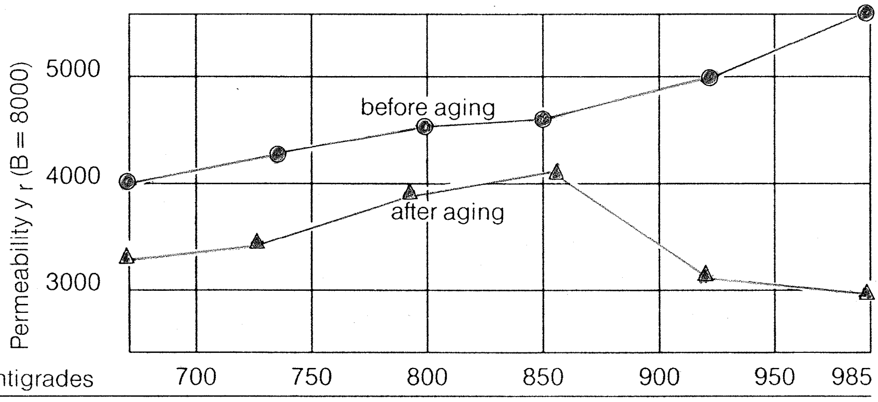
Relative Permeability µr

		H [A/cm] =				
Pr.-Nr.		25	50	100	200	300
1 1	B [T] µr	1.62 516	1.73 275	1.84 146	1.97 78	2.04 54
2 2	B [T] µr	1.61 512	1.73 275	1.84 146	1.97 78	2.04 54
3 3	B [T] µr	1.67 531	1.74 277	1.84 146	1.97 78	2.06 55
4 4	B [T] µr	1.67 531	1.74 277	1.84 146	1.97 78	2.06 55
5 5	B [T] µr	1.65 525	1.73 275	1.83 146	1.96 78	2.05 54
6 6	B [T] µr	1.65 525	1.73 275	1.83 146	1.96 78	2.05 54
7 7	B [T] µr	1.66 528	1.73 275	1.83 146	1.97 78	2.05 54
8 8	B [T] µr	1.65 525	1.72 274	1.82 145	1.96 78	2.05 54
9 9	B [T] µr	1.56 496	1.70 270	1.82 145	1.96 78	2.05 54
10 10	B [T] µr	1.56 496	1.70 270	1.82 145	1.96 78	2.05 54
11 11	B [T] µr	1.65 525	1.74 277	1.85 147	1.98 79	2.06 55
12 12	B [T] µr	1.64 522	1.72 274	1.82 145	1.96 78	2.05 54
13 13	B [T] µr	1.65 525	1.72 274	1.83 146	1.96 78	2.05 54
14 14	B [T] µr	1.65 525	1.72 274	1.83 146	1.96 78	2.05 54
15 15	B [T] µr	1.66 528	1.73 275	1.83 146	1.96 78	2.05 54
16 16	B [T] µr	1.66 528	1.73 275	1.83 146	1.96 78	2.05 54
17 17	B [T] µr	1.58 503	1.70 270	1.81 144	1.95 78	2.04 54
18 18	B [T] µr	1.58 503	1.70 270	1.82 145	1.96 78	2.04 54
19 19	B [T] µr	1.63 519	1.70 270	1.81 144	1.95 78	2.04 54
20 20	B [T] µr	1.61 512	1.69 269	1.80 143	1.95 78	2.04 54

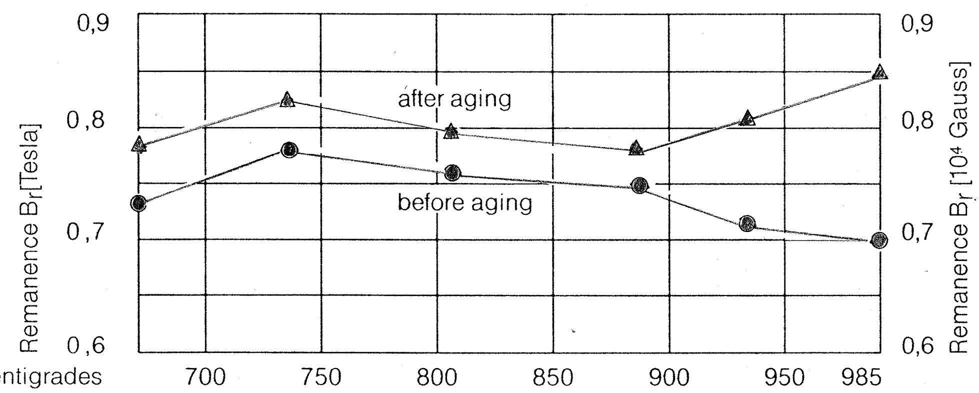
Material Test: V42/80, Thyssen Stahl AG 14.2.1991
Measurements of cylinder samples 60mm * 13.5 mm rd.

Effect of annealing temperature on magnetic properties

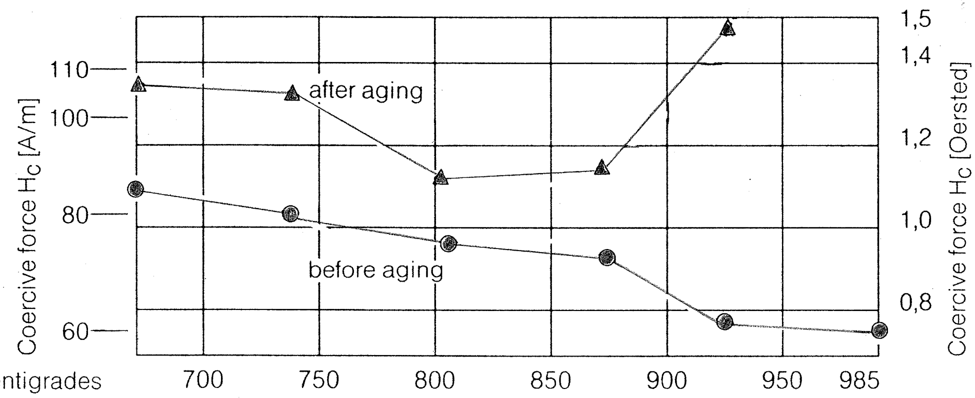
Effect of annealing temperature* on permeability



Effect of annealing temperature* on remanence



Effect of annealing temperature* on coercive force



*Aging 220 hours at 150°C

Corrosion Resistance

The behaviour of iron and steel against corrosion largely depends on the purity of the material. The purer the iron is, the greater is its resistivity against electrolytic self-destruction, which takes place at the border areas between the iron crystals and the other elements. With regard to rusting, **ARMCO Pure Iron** is superior to normal unalloyed steels, since it forms cohesive and adhesive rust layers, which protect the metal underneath from further attack.

Years of experience have confirmed that **ARMCO Pure Iron** resists destruction by rust and corrosion longer and better than unalloyed steels.

ARMCO Pure Iron is resistant to acids, bases and salt solutions associated with chemical compounds related to the element Fe. Although **ARMCO Pure Iron** cannot replace a rust- and acid-resistant material, it nevertheless offers advantages wherever a certain level of chemical attack has to be accepted in case of the use of unalloyed metallic materials.

Thanks to its homogenous structure and high level of purity, **ARMCO Pure Iron** is attacked by many iron-decomposing chemicals more slowly than unalloyed steels.

Trial:

Comparative trial of **ARMCO Pure Iron** and construction steel S235JR (St-37) with regard to the erosion rate on perforated plates for galvanisation baths or etching baskets.

	Sample – No.	Weight of Sample		Weight Loss		
		condition of delivery	after pckling	in g	in %	average %
ARMCO Pure Iron	1	702,8 g	689,9 g	12,9	1,84	2,15
	2	732,5 g	717,6 g	14,5	1,98	
	6	728,0 g	708,9 g	19,1	2,62	
S235JR	3	848,3 g	820,1 g	28,2	3,32	3,65
	4	734,8 g	706,9 g	27,9	3,80	
	5	702,0 g	675,2 g	26,8	3,82	

Trial: Verzinkerei Lenzburg, 9.6.1989

The trial shows that **ARMCO Pure Iron** demonstrates slow erosion rates in comparison to S235JR (St 37) of 41 %.

Oxidation Resistance

In a similar way to corrosion, oxidation (scaling) also depends heavily on the purity of the material. Oxidation is important in heat treatment and other stresses caused by heat. The scaling caused by oxidation not only impairs the heat transmission, but also reduces the material thickness, thus having a destructive effect. As in the case of rust attack, **ARMCO Pure Iron** demonstrates greater resistance by the formation of adhering, protective layers of scale, while more impure, normal steel forms relatively thick and loose layers of scale, which become easily detached and then form again.

Processing

Non-cutting forming

The purity of **ARMCO Pure Iron**, particularly with regard to strengthening elements, results in a high level of softness and cold forming capability (reduction in area approx. 90%). Non-cutting cold forming processes (cutting, drawing, deep-drawing, pressing and cold forging) therefore produce only minor compressive strain and form change resistances, which enable high forming levels. Under controlled forming, the tensile strength can increase to double the initial value.

Hot forming by rolling, forging, bending, border crimping and compressing should not be carried out in the red shortness area between 850 – 1050 °C.

Machining

Turning - Both high-speed steel and hard metal tools can be used for machining **ARMCO Pure Iron**. Sharply ground tools and carefully selected cutting data are particularly important, since in the case of incorrect selection, **ARMCO Pure Iron** 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, the turned surface has a gloss appearance, and otherwise matt. An extremely fine cutting surface is also important. 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 % sulphur and 5 % grease.

Milling – In order to obtain a fine surface, cylindrical milling cutters with a pitch angle of 45 - 52° are recommended. The radial cutting angle should be 30°. At cutting speeds of 25 - 45 m/min, a feed of 19 - 32 mm/m should be selected. The use of side milling cutters requires a radial cutting angle of 10°. A clean swarf gap shape of the tools must be ensured. 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 approx. 0.05- 0.10 mm/rev.

Welding

An iron which is as metallurgically pure as **ARMCO Pure Iron** also has excellent welding characteristics. This applies both for arc-welding and for the autogen process. The finished weld seam needs no subsequent treatment. It is also possible to take advantage of the benefits of welding rods made of **ARMCO Pure Iron** for the production of weld connections to normal construction steels. The characteristic features of **ARMCO Pure Iron** also come into their own in the form of welding wire for repair work to cast components.

Heat Treatment

The following data are recommended for the heat treatment of **ARMCO Pure Iron**:

Normalising	950 °C, holding time approx. 1 min/mm, at least 30 min, furnace cooling
Soft Annealing	Normalising + tempering at 820 °C, holding time 2 min/mm, air cooling Recommended heat treatment for achieving hardness values below 90 HB (max.)
Stress Relieving	Approx. 650 °C, holding time approx. 1 min/mm (until thorough heating), followed by even cooling to below 300 °C (furnace cooling).
Recrystalisation Annealing	680 – 700 °C, as intermediate annealing after cold forming or cold drawing, or between the individual forming stages
Final Annealing*	800 – 850 °C, very slow cooling down to 600 °C at approx. 1 – 5 °C/min.

*To remove residual stress after strain hardening and to improve the structure with regard to grain size and grain structure, the finished part should undergo final annealing (800 – 850°C) following the last mechanical processing stage. Annealing above this temperature usually results in deterioration of the magnetic and the mechanical properties, which is caused by the accumulation of alloy additions at the grain boundaries. When exceeding the A_3-point a refinement of the structure occurs; this must be avoided to maintain good magnetic properties. The cooling speed should be "slow" at least down to 600 °C, which corresponds to a guiding value of approx. 1 – 5 °C/minute. There is no known relationship of the properties to the cooling speed below 600 °C.

Hydrogen has proven to be a good annealing atmosphere, although the heat treatment can also be carried out under vacuum.

To achieve the best values of individual physical properties, e.g. the electrical resistivity, a heat treatment of 3 hrs at 600 °C in a vacuum with furnace cooling have proven to be advantageous..

If the lowest possible coercive force is required, annealing should be carried out at 850 °C in humid H_2/Ar (20 / 80 %) after preceding 10 % cold forming. The grain sizes achieved by this process are between 0.2 and 0.8 mm average diameter.