MUMETAL – PERMIMPHY
SUPERMIMPHY
Fe-Ni SOFT MAGNETIC ALLOYS

I. INTRODUCTION

Mumetal, Permimphy and Supermimphy are the crystalline soft magnetic alloys with :

- the highest permeabilities
- the lowest coercive fields
- the lowest magnetic losses.

The table below gives their nominal composition in weight % :

Ni	Mo	Si	Mn	C	Fe
80-81	4.5-6	0.05-0.4	0-0.5	0.01	balance

II. APPLICATIONS

The principal applications for these alloys are :

- High performance magnetic cores, produced as stacked profiled laminations or toroids (wound tape or stacked rings). The uses of these magnetic cores include measuring instruments, ground fault circuit breakers and line transformers for computer modems.
- Magnetic shielding, to protect certain components and sub-assemblies from disturbance by extraneous magnetic fields, or for the manufacture of screened chambers, in medical apparatuses, for example.
- In the field of electrical safety, high sensitivity relay components for ground fault circuit breakers.
- Magnetic sensors : reading and recording heads for magnetic tape systems.
- Current sensors, with or without a Hall effect probe.
- All applications requiring the use of a high permeability magnetic material, with a low coercive field and low losses, in the range from low frequencies up to 1 MHz.

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III. PRODUCT RANGE

Imphy Alloys offers a complete range of Fe-Ni grades centred on the 80% Ni composition. The alloy chemistries and manufacturing processes have been specially designed to enhance certain characteristics, depending on the intended application :

- Optimum magnetic properties
- Ease of fabrication (stampability, drawability, etc.)
- Stability of the magnetic properties with temperature
- Good stability of the magnetic properties under mechanical loading.

III. 1. MUMETAL

This grade covers the majority of common applications, both for shielding and for magnetic cores, due to a maximum relative permeability in continuous fields of up to 350 000 and a coercive field level of 0.6 A/m (typical values measured on 1.5 mm thick strip).

III. 2. PERMIMPHY

This grade, which is obtained using special refining conditions, offers magnetic properties as high as those of Mumetal together with an excellent aptitude for the large series mechanical stamping of profiles.

III. 3. SUPERMIMPHY

These grades represent the highest level of magnetic properties.

In the form of finished tape wound cores made from strip less than 0.10 mm (0.004'') thick, the maximum relative impedance permeability at 50 Hz μ_{maxz} reaches 400 000.

There are two Supermimphy grades, a standard alloy Supermimphy L and a « Low Stress » version Supermimphy LLS. The chemical composition of the latter alloy is specifically adjusted to limit the deleterious effect of mechanical stresses occurring in service, after heat treatment. A typical case is the application of a resin coating to protect components such as current sensors or computer modem line transformers.

IV. PHYSICAL PROPERTIES

	Typical values	Units
Density*	8.7	$g.cm^{-3}$
Specific heat*	460	$J.kg^{-1}.℃^{-1}$
Thermal conductivity*	19	$W.m^{-1}.℃^{-1}$
Mean CTE between -50 ℃ and +200 ℃	12.10^{-6}	$℃^{-1}$
Electrical resistivity*	60	µΩ.cm
Curie point	420	℃
Coefficient of magnetostriction at saturation * $\frac{\Delta\ell}{\ell}$	1-3	10^{-6}
Melting temperature	1450	℃

* measured at ambient temperature

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V. FINAL HEAT TREATMENT

The optimum magnetic properties of the Mumetal, Permimphy and Supermimphy grades are obtained only after high temperature heat treatment of the finished sheets or parts.

The principal aim of this treatment, which is essential, is to recrystallize the material.

The final heat treatment must imperatively be performed under appropriate conditions, according to the recommendations given below.

V. 1. ATMOSPHERE

Hydrogen, which helps to reduce certain residual impurities, is the best protective atmosphere.

However, cracked ammonia and vacuum are alternative possibilities.

All necessary precautions must be taken to eliminate the risk of contamination, particularly by oxygen and water vapour. The parts to be treated must be thoroughly cleaned and degreased. The inert powder (alumina, magnesia) often used to isolate the parts must be perfectly anhydrous.

In all cases, the dew point inside the furnace must be less than –40 ℃.

In practice, a hydrogen flow rate of the order of 5 volumes/hour is employed, and if necessary, a holding shelf at around 400℃ is incorporated in the heating cycle to guarantee that the dew point in the furnace is correct.

V. 2. TEMPERATURES

Imphy Alloys recommends holding for 2 to 6 hours at 1 100 – 1 175℃. The heating rate has little influence on the magnetic properties. In contrast, a lower heat treatment temperature will adversely affect the permeability level.

V. 3. COOLING RATE

The cooling rate determines the degree of short range ordering of the atoms and therefore has a marked influence on the permeability of the Fe-80% Ni alloys.

In the majority of ordinary cases, simple furnace cooling is sufficient, provided that the cooling rate is of the order of 100 to 300℃/h between 600 and 300℃.

However, to optimize certain magnetic properties, such as the initial permeability or the rectangularity of the hysteresis cycle, or to reduce variations in permeability around ambient temperature, it may be necessary to accurately adjust the cooling conditions between 600℃ and 300℃.

A good practical solution is to allow the parts to cool slowly in the furnace down to a holding temperature situated between 400 and 520℃, followe d by holding for about 1 hour, then to rapidly remove them from the furnace in order to finish the treatment with a high cooling rate (of the order of 1000℃/h). The value of the holding temperature dep ends on the desired magnetic properties.

Another possibility is to perform a second treatment, typically of 1 hour at about 500℃, followed by rapid quenching (1000℃/h), after the initial high temperature treatment (2 to 6 hours at 1 100 – 1 175℃).

V. 4. OXIDATION TREATMENT

For certain applications, the parts must be covered with a thin layer of oxide (e.g. electrical insulation of Mumetal profiles).

In this case, during the final stage of the heat treatment, the protective atmosphere is replaced by an atmosphere with a controlled oxidizing potential (for example, holding in air for 1 hour at about 500℃).

V. 5. CUSTOM HEAT TREATMENT

When the magnetic property requirements are particularly demanding, Imphy Alloys can place its extensive experience in the heat treatment of magnetic alloys at the user’s disposal. Moreover, IUP’s subsidiary MECAGIS possesses a range of high performance heat treatment equipment devoted to magnetic alloys, and can perform heat treatments for customers on any parts whose magnetic properties must be optimized.

VI. MAGNETIC PROPERTIES

The tables below give typical values of the magnetic properties measured after heat treatment, in compliance with the standards:

- ASTM AS96
- DIN 50560
- IEC 60404

VI. 1. DIRECT CURRENT

Measurements made on 35*26*0.34 mm ring specimens after heat treatment for 4h at 1170℃, followed by cooling at 200℃/h.

Grade	Bs (1) (Tesla)	Br (2) (Tesla)	Hc (2) (A/m)	μ_4 (3)	μ_{max}
Mumetal	0.76	0.5	0.6	120000	350000
Permimphy	0.75	0.45	0.65	150000	320000
Supermimphy L	0.75	0.4	0.35	550000	570000
Supermimphy LLS	0.7	0.23	0.4	285000	300000

(1) practical saturation measured for H = 800 A/m.

(2) remanent induction B_r and coercive field H_c measured from H = 80 A/m.

(3) measured for H = 4 mA/cm (peak value)

On massive products : DC measurements made on 24*20*10 mm cores

Grade	Heat treatment	Bs (1) (Tesla)	Hc (2) (A/m)	μ_{zmax}
Permimphy	1050℃ under vacuum	0.73	19	150000
	4h 1170℃ in H2	0.73	10	300000

(1) practical saturation measured for H = 80 A/m.

(2) coercive field H_c measured from H = 80 A/m.

VI. 2. 50-60 Hz ALTERNATING CURRENT

Measurements made on 36*25*0.34 mm ring specimens after heat treatment for 4h at 1170℃, followed by cooling at 200℃/h.

Grade	μ_{4z} (1)	μ_{zmax}
Mumetal	50000	95000
Permimphy	50000	80000
Supermimphy L	70000	95000
Supermimphy LLS	70000	85000

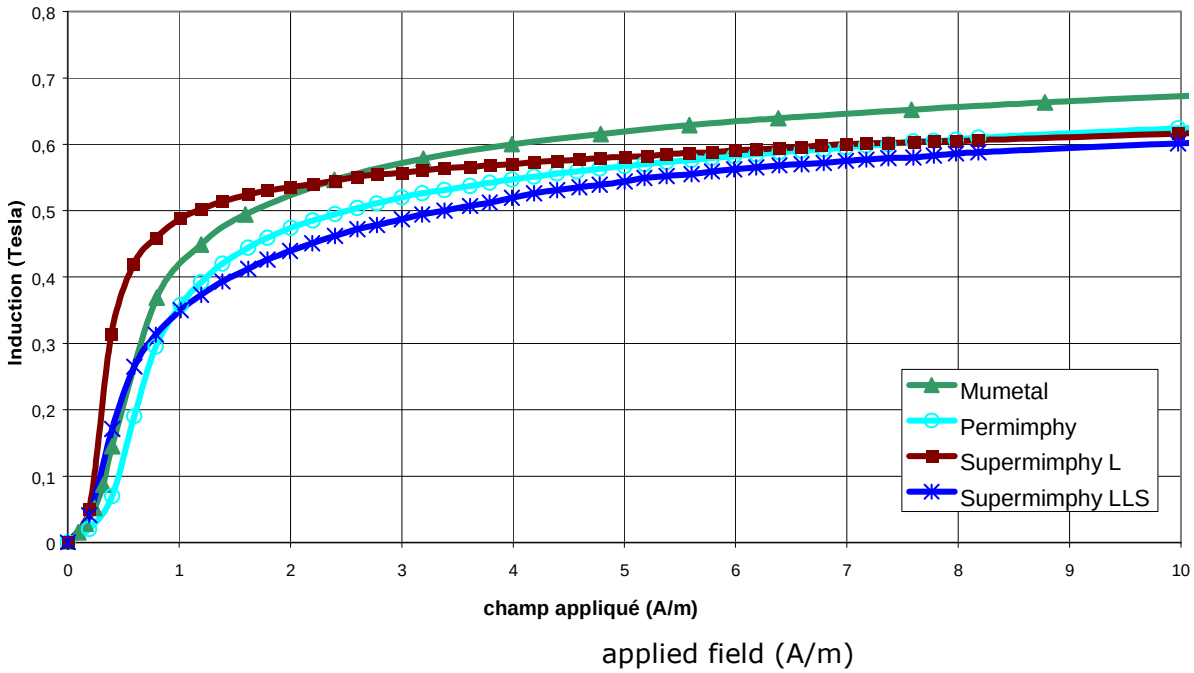
(1) sinusoidal excitation field H = 4 mA/cm (peak value)

Measurements made on 30*20*0.07 mm toroidal cores after heat treatment for 4h at 1170℃ and optimum arrest temperature

Grade	μ_{4z} (1)	μ_{zmax}
Supermimphy L/LLS	340000	400000

(1) sinusoidal excitation field H = 4 mA/cm (peak value)

VII. TYPICAL MAGNETIZATION CURVES



applied field (A/m)

DC magnetization curves for Mumetal, Permimphy, Supermimphy L and Supermimphy LLS.

On request, Imphy Alloys can provide customers with the data points corresponding to these curves in computer format.

VIII. MECHANICAL PROPERTIES

VIII. 1. COLD ROLLED STRIP

The figures given below are typical values, for measurements made in compliance with the standards :

- NF EN 10002 for tensile tests
- EN ISO 6507 for hardness measurements
- NFA 04102 for grain size measurements.

Property	Cold worked condition	Annealed condition	Finished parts treated at 1 170℃
Hardness (HV)	325	160	110
UTS (MPa)	1050	650	530
0.2% PS (MPa)	1030	280	160
Elongation (%)	3	35	45
Grain size	_	8	0-3

On request, Imphy Alloys can supply non-standard conditions when required by the customer.

VIII. 2. MASSIVE PRODUCTS

Property	As-hot processed condition (bars, sheets, forgings)
Hardness (HV)	150 +/- 50
Grain size	4 - 10

On request, Imphy Alloys can supply non-standard conditions when required by the customer.

IX. IMPLEMENTATION

IX. 1. CUTTING AND SHEARING

Cutting operations are generally performed in the cold worked condition.

IX. 2. BENDING, DEEP DRAWING, STRETCHING, LATHE SPINNING, STAMPING

For these forming processes, the metal is used in the softened condition, i.e. after having received an annealing treatment.

Depending on customer requirements, Imphy Alloys can adapt the softening treatment for bending or deep drawing operations.

When the annealed metal is subjected to significant plastic strain, work hardening occurs, whose extent can be estimated from the following table:

Plastic strain (% reduction in thickness)	10	25	50	75
Hardness (HV)	220	270	300	330
UTS (MPa)	686	834	981	1079
Elongation (%)	25	10	4	2

An intermediate softening treatment may sometimes prove necessary during the forming sequence.

Imphy Alloys recommends the following procedure : holding for a minimum of 1 hour at 850 – 900°C. It is essential to take all necessary precau tions to prevent contamination of the metal, including a clean furnace and clean parts and a protective atmosphere with a dew point less than –40°C.

IX. 3. MACHINING

The behaviour of Mumetal, Permimphy and Supermimphy differs from that of stainless steels : they are « sticky » alloys whose chips tend to adhere to the tool. Relatively slow cutting speeds must therefore be employed :

	Turning	Milling	Drilling
Tool	High speed steel	High speed steel	High speed steel
Lubricant	Soluble or whole oil	Soluble or whole oil	Soluble or whole oil
Cutting angle (°)	10	10	-
Rake angle (°)	6	6	6
Cutting speed (m/minute)	25	25	15
Advance rate (mm/rev)	0.25	-	0.10

The use of a carbide tool enables these cutting speeds to be doubled.

The parts must be thoroughly cleaned after machining to avoid all risk of contamination.

IX. 4. WELDING

The rules for welding Mumetal and Permimphy are similar to those for austenitic stainless steels.

Imphy Alloys recommends welding without filler metal. Resistance spot welding is by far the most common technique employed, but electron beam and argon arc welding are also possible.

Welding should normally be carried out before final heat treatment of the parts, even in the case of spot welding.

IX. 5. BRAZING

It is imperative to perform brazing after the final high temperature heat treatment.

The magnetic properties in the braze zones are usually impaired.

IX. 6. CORROSION RESISTANCE

The corrosion resistance of Mumetal, Permimphy and Supermimphy is better than that of carbon steels, due to their high nickel content. However, they are not stainless and their oxidation resistance must be verified in each particular case.

X. AVAILABLE FORMATS

Grade	Treated cores (1)	Treated parts (1)	Cold rolled strip	Long and massive products (2)
Mumetal	∎	∎	∎	
Permimphy	∎	∎	∎	∎
Supermimphy L	∎	∎	∎	
Supermimphy LLS	∎	∎	∎	

(1): profiles, stacked laminations, rotor and stator sheets, shielding, plates for chemical machining sold by MECAGIS, a subsidiary of Imphy Ugine Précision.

(2) : bars, profiled sections, forgings, hot rolled sheets

X. 1. FLAT PRODUCTS

Format	Thickness (mm)	Maximum width (mm)	Condition
Cold rolled strip delivered in coils	0.025 to 0.07	300	Cold worked or annealed
	0.07 to 3	640	Cold worked or annealed
Cold rolled strip delivered as cut-to-length sheets (maximum length 3500 mm)	0.1 to 3	10 to 640	Cold worked or annealed
Hot rolled sheets	5 to 50	500 to 2 000	As-rolled and pickled

Please consult Imphy Alloys for specific requirements.

X. 2. BARS

Diameter ϕ (mm)	Standard lengths (mm)
$\Phi \leq 13$	2000 to 3000
$14 \leq \Phi \leq 80$	3000 to 4000
$\Phi > 80$	Dependent on the diameter and the quantity ordered

Please consult Imphy Alloys for specific requirements.

X. 3. FORGINGS AND CASTINGS

Study on request.