WEIGHTS AND MASS STANDARDS

IN ACCORDANCE WITH THE

OIML R111: 2004

MADE BY

HÄFNER
THE PERFECT WEIGHT

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Perfect Weights and mass standards made by HÄFNER

1. Use of weights

- for adjustment, calibration and verification of weighing instruments;
- for adjustment, calibration and verification of weights of a lower class of accuracy;
- with weighing instruments.

Weights are distinguished to different accuracy classes. The accuracy classes E1, E2, F1, F2, M1, M2, M3 are defined in the international recommendation OIML R111. Some national norms (e.g. ASTM 617 in USA) have defined other classes (e.g. ASTM 617, classes 0, 1, 2, 3, 4, 5, 6, 7).

Notice: Häfner manufactures weights in accordance with OIML R111, ASTM 617 or other national rules.

The OIML weight classes are defined as follows:

a. **Class E_1 Weights:** weights intended to ensure traceability between national mass standards (with values derived from the International Prototype of the kilogram) and weights of class E_2 and lower. Class E_1 weights or weight sets shall be accompanied by a calibration certificate.

b. **Class E_2 Weights:** weights intended to be used for the initial verification of class F_1 weights and intended to be used with weighing instruments of accuracy class I. Class E_2 weights or weight sets shall always be accompanied by a calibration certificate. They may be used as class E_1 weights if they comply with the requirements for surface roughness and magnetic susceptibility and magnetization for class E_1 weights and their calibration certificate.

c. **Class F_1 Weights:** weights intended to be used for the initial verification of class F_2 weights and intended to be used with weighing instruments of accuracy class I and II.

d. **Class F_2 Weights:** weights intended to be used for the initial verification of class M_1 and possibly M_2 class weights, intended to be used for important commercial transactions (e.g. gold and precious stones) on weighing instruments of accuracy class II.

e. **Class M_1 Weights:** weights intended to be used for the initial verification of class M_2 weights, intended to be used with weighing instruments of accuracy class III.

f. **Class M_2 Weights:** weights intended to be used for the initial verification of class M_3 weights, intended to be used in normal commercial transactions and on weighing instruments of accuracy class III.

g. **Class M_3 Weights:** weights intended to be used on weighing instruments of accuracy classes IIII.

2. Units and nominal values

Following SI-units are used:

- for mass: milligram → mg
  gram → g
  kilogram → kg
- for density: kilogram per cubic meter → kg/m³

The nominal values of the mass for weights shall be equal to 1×10^n kg, 2×10^n kg, 5×10^n kg.

Häfner manufactures also weights with other nominal values (e.g. 2,5 g) and units (e.g. "N" for testing a force, "oz" and "lb" according ASTM 617) for the customer's use.

3. Construction, shape and design

Häfner fulfils all requirements for the construction of weights as given by the International Recommendation OIML R111.

class E1 and E2:
- solid, no cavities, single piece of one material

class F1 and F2:
- one or more pieces of the same material
- adjusting cavity is allowed
- shall be sealed by a knob or other suitable device

class M1, M2 and M3:
- 1 g – 10 g: adjusting cavities are not recommended
- 20 g + 50 g: adjusting cavities are optional
- 100 g – 5000 kg: shall have adjusting cavities

By Häfner customers also can order special constructions, shapes and designs for their weights.

Standard weights shall have
- a simple shape
- no sharp edges
- no pronounced hollows

weights of 1 g or less:
- sheet weights
- wire weights

Häfner customers can choose fraction weights between sheet or wire weights.
Also special designs are possible.

nominal value	shape	
	sheet weights	wire weights
1-10-100-1000 mg	triangle	triangle or 3 segments
2-20-200 mg	square	square or 4 segments
5-50-500 mg	pentagon	pentagon or 5 segments

Weights of 1 g and larger:
For weights of 1 g and larger Häfner manufactures all shapes in below table.
If you require special designs please contact us.

shape	OIML R111						
	Class M3	Class M2	Class M1	Class F2	Class F1	Class E2	Class E1
knob weights	X	X	X	X	X	X	X
cylinder weights				X	X	X	X
disc weights				X	X	X	X
hooked weights	X	X	X	X			
handle weights	X	X	X	X	X	X	X
slotted weights	X	X	X	X	X		
block weights	X	X	X	X	X	X	X
rolling weights	X	X	X				
carrier weights	X	X	X	X			

4. Characteristics of the Materials

The weights shall be corrosion resistant. The quality of the material shall be such that the change in the mass of the weights shall be negligible in relation to the maximum errors permitted in their accuracy class under normal conditions of use and the purpose for which they are being used.

Class E1 and E2:

- hardness and resistance to wear shall be similar or better than that of austenitic stainless steel.

Class F1 and F2:

- hardness and brittleness of the materials shall be at least equal to that of drawn brass.

Class M1:

- resistance to corrosion and brittleness of block weights from 5 kg – 50 kg shall at least equal to that of cast iron.
- Cylindrical weights 1 g – 20 kg shall be made of brass or similar or better than that of brass. Surface treatment is permitted.
- Weights less than 1 g: material shall be resistant to corrosion and oxidisation; surface shall not be coated.

Class M2 and M3:

- Cast iron shall not be used for weights less than 100 g.
- Hardness and corrosion resistance of cylindrical weights, 1 g – 20 kg ,shall be at least that of brass and brittleness not exceeding that of cast iron. Surface treatment is permitted.
- Weights less than 1 g: material shall be resistant to corrosion and oxidisation; surface shall not be coated.

Magnetization and Susceptibility

The magnetization and susceptibility should not exceed the maximum values given in following tables.

Maximum Permanent Magnetization, $\mu_0 M$ (µT)

Weight Class	E_1	E_2	F_1	F_2	M_1	M_2	M_3
Maximum Magnetization, μ_0M (µT)	2.5	8	25	80	250	800	2500

Maximum Susceptibility, χ

Weight Class	E_1	E_2	F_1	F_2
m ≤ 1 g	0.25	0.9	10	-
2g ≤ m ≤ 10 g	0.06	0.18	0.7	4
20 g ≤ m	0.02	0.07	0.2	0.8

If the values of all local measurements of magnetization and susceptibility are less than these limits, then it may be assumed that the uncertainty components due to the magnetism of the weight are negligible. The maximum permanent magnetization and magnetic susceptibilities and given in Tables 4 and 5 are such that, at magnetic fields and magnetic field gradients possibly present on balance pans, they produce a change of the conventional mass of less than 1/10 of the maximum permissible error of the test weight.

Density

The density of the material used for weights shall be such that a deviation of 10 % from the specified air density (1,2 kg m³) does not produce an error exceeding 1/4 of the maximum permissible error. These limits are given in the following table:

Nominal value	ρ_{min}....ρ_{max} (10^3 kg m³)					
	Class E1	Class E2	Class F1	Class F2	Class M1	Class M2
≥ 100 g	7,934.....8,067	7,81.....8,21	7,39.....8,73	6,4...10,7	≥ 4,4	≥ 2,3
50 g	7,92.....8,08	7,74.....8,28	7,27.....8,89	6,0...12,0	≥ 4,0	
20 g	7,84.....8,17	7,50.....8,57	6,6...10,1	4,8...24,0	≥ 2,6	
10 g	7,74.....8,28	7,27.....8,89	6,0...12,0	≥ 4,0	≥ 2,0	
5 g	7,62.....8,42	6,9.....9,6	5,3...16,0	≥ 3,0		
2 g	7,27.....8,89	6,0...12,0	≥ 4,0	≥ 2,0		
1 g	6,9.....9,6	5,3...16,0	≥ 3,0			
500 mg	6,3...10,9	≥ 4,4	≥ 2,2			
200 mg	5,3...16,0	≥ 3,0				
100 mg	≥ 4,4	≥ 2,3				
50 mg	≥ 3,4					
20 mg	≥ 2,3					

Used materials by Häfner weights

Identi-fication	Material	Used classes	Used nominal values	Density at 20 °C	Uncertainty of density U (k=2)	Magnetization $\mu_0 M$ (µT)	Magnetic susceptibility χ	Hardness
GG25	cast iron	M3, M2, M1	100 g - 2000 kg	7200 kg/m³	+/- 400 kg/m³	-	-	ca 240 HB
ST	steel	M3, M2, M1	1 kg - 5000 kg	7850 kg/m³	+/- 200 kg/m³	-	-	ca 140 HB
MS58	special brass, finely turned	M3, M2, M1	1 g - 20 kg	8400 kg/m³	+/- 100 kg/m³	0,05 - 4	< 0,03	ca. 150 HB
MS58N	special brass, nickel-plated	M3, M2, M1	1 g - 20 kg	8400 kg/m³	+/- 100 kg/m³	1 - 20	< 0,08	550 HV Schichthärte
AL99	aluminium	M1 - E1	sheet and wire weights: 1 mg - 5 mg	2650 kg/m³	+/- 130 kg/m³	0,01 – 0,5	< 0,01	
NS48	nickel silver	M2 - E2	sheet weights: 10 mg - 500 mg	8600 kg/m³	+/- 170 kg/m³	0,05 - 2	< 0,01	170 HV
MS58M	special brass, miralloy-plated	F2, F1	1 g - 20 kg	8400 kg/m³	+/- 100 kg/m³	0,05 - 4	< 0,03	550 HV Schichthärte
HF12	austenitic stainless steel	F2, F1, E2	1 g - 2000 kg	7950 kg/m³	+/- 100 kg/m³	0,05 – 1,5	< 0,03	ca 110 HB
HE210	special weight steel	E2, E1, E0	wire weights: 1 mg - 500 mg sheet weights: 10 mg -500 mg and 1 g - 2000 kg	8000 kg/m³	+/- 15 kg/m³	0,01 – 0,5	0,002 - 0,004	160 - 240 HB

Austenitic stainless steel: HF12

The austenitic stainless steel HF12 is a corrosion-resistant material and has a good polishability.
HF12 meets all requirements of **OIML R111, class E2, F1** and **F2**.

A feature of this stainless steel is the **magnetic properties (susceptibility and magnetisation)**. Because of these small values the material is used for weights and mass standards in general industry, chemical and pharmaceutical industries and in many state offices for measures and metrology.

HF12 affords a good **long-time stability.**

Häfner uses this steel for weights and mass standards of class E2, F1 and F2.
The following properties show the high quality of this stainless steel.

Physical characteristics

density kg/m³	Susceptibility of volume χ	Magnetisation $\|\mu_0 M\|$ / µT	Coefficient of linear thermal expansion at 20 °C	Coefficient of thermal volume expansion at 20 °C
7950 +/- 100	0,005 - 0,02	0,05 - 4	16,0 * 10^{-6} m / (m*K^{-1})	48,0 * 10^{-6} K^{-1}

Heat conductivity at 20 °C W/(m*K)	Specific heat at 20 °C J/(kg*K)	Electrical resistance at 20 °C Ohm*mm² / m	Modulus of elasticity [kN / mm²] at					
			20 °C	100 °C	200 °C	300 °C	400 °C	500 °C
15	500	0,73	200	194	186	179	172	165

Mechanical characteristics

R_m tensile strength N/mm²	Hardness HB	Polishability, Grain size according to ASTM E 112
500 - 700	130 - 190	6 or finer

type of product	direction of testing	$R_{p\ 0,2}$ proof stress N/mm²	$R_{p\ 1,0}$ proof stress N/mm²	A_5 elongation % min.	A_V average value of notched bar impact work, J min.
Bars < 160 mm	longitudinal	195	230	35	85
Bars > 160 mm and sheets or plates < 50 mm	transversal			35	55

Limits of chemical composition (reference data for information purposes)

proof		by weight in %										
		C	Si	Mn	P	S	Cr	Mo	Ni	Cu	N	Ti
melting	min.						16		8			
analysis	max.	0,07	0,5	2,0	0,05	0,01	20	3,0	14	0,5	0,3	0,2

Special weight steel: HE210

Austenitic stainless steel HE210 is a highly corrosion-resistant material.
Häfner has further modified this stainless steel with special characteristics for the use as a special 'weight' steel.
HE210 meets all requirements of **OIML R111, class E1** and also of the theoretical class **"E0"** (primary mass standards).

A superior feature of HE210 is the small uncertainty of the **density**. Consequently every manufactured batch is close to **8000 kg/m³.** A further quality of this stainless steel is the **magnetic properties (susceptibility and magnetisation)**. These values are small, allowing the material to be used for primary mass standards in many national institutes of metrology.

Resulting from the special vacuum melting and remelting production this steel has many advantages over standard stainless steels:

- Optimum homogeneous ingot structure
  (minimum segregation levels, uniform density, absence of pipes and discontinuities)
- Minimum gas contents
- Minimum of contents of trace elements (such as As, Sb, Sn etc.)
- Minimum contents of nonmetallic inclusions
- Highly uniform distribution of any remaining inclusions
- Optimum polishability,
  smallest grain size according to ASTM E112: grain size 6 or finer
- Virtually isotropic properties (particularly as regards toughness)
- High reproducibility thanks to process automation

HE210 is very resistant to pitting and stress corrosion cracking and to general corrosion. Consequently those weights and mass standards made of HE210 have a very good **long-time stability.**

Häfner employs this excellent steel for weights and mass standards of class E0, E1 and optionally for class E2.
The following properties shows the high quality of this steel.

Physical characteristics

density kg/m³	Susceptibility of volume χ	Magnetisation $\|\mu_0 M\|$ / µT	Coefficient of linear thermal expansion at 20 °C	Coefficient of thermal volume expansion at 20 °C
8000 +/- 15	0,002 - 0,004	0,01 – 0,5	15,5 * 10^{-6} m / (m*K^{-1})	46,5 * 10^{-6} K^{-1}

Heat conductivity at 20 °C W/(m*K)	Specific heat at 20 °C J/(kg*K)	Electrical resistance at 20 °C Ohm*mm² / m	Modulus of elasticity [kN / mm²] at					
			20 °C	100 °C	200 °C	300 °C	400 °C	500 °C
12	450	1,0	197	191	184	175	170	163

Mechanical characteristics

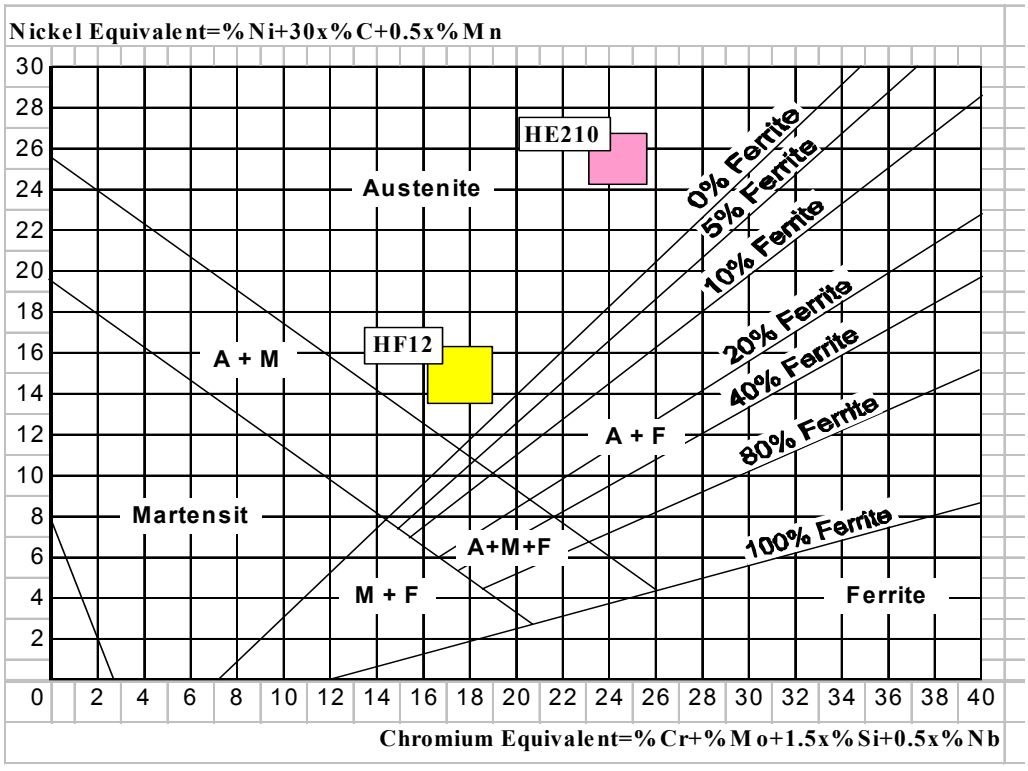
R_m tensile strength N/mm²	Hardness HB	Polishability, Grain size according to ASTM E 112
530 - 730	160 - 240	6 or finer

type of product	direction of testing	$R_{p\ 0,2}$ proof stress N/mm²	$R_{p\ 1,0}$ proof stress N/mm²	A_5 elongation % min.	A_V average value of notched bar impact work, J min.
Bars < 160 mm	longitudinal	230	260	40	100
Bars > 160 mm and sheets or plates < 50 mm	transversal			35	60

Limits of chemical composition (reference data for information purposes)

proof		by weight in %										
		C	Si	Mn	P	S	Cr	Mo	Ni	Cu	N	Ti
melting	min.						17	2,0	20	0,5		
analysis	max.	0,03	1,0	3,0	0,05	0,01	26	6,5	28	2,5	0,3	0,2

Schaeffler-Diagram



5. Surface Conditions

Under normal use, the surface qualities shall be such that any alteration of the mass of the weights is negligible with respect to the maximum error.

Class E1, E2, F1 and F2:

The surface of the weights (including the base and corners) shall be smooth and the edges shall be rounded. The weights shall not appear to be porous and shall present a glossy appearance. Weights of class E1 and E2 shall have no surface coatings. At Weights of class F1 and F2 a metalized surface coating is allowed.

In case of doubt the following maximum values of surface roughness are given:

Class	E1	E2	F1	F2	
Rz (µm)	0,5	1	2	5	
Ra (µm)	0,1	0,2	0,4	1	
Rz (µm) by Häfner	0,1 – 0,15	0,15 – 0,3	0,2 – 0,5	polished	fine grinted
				0,2 – 0,5	1,5 – 3
Ra (µm) by Häfner	0,02 – 0,03	0,03 – 0,06	0,04 – 0,1	polished	fine grinted
				0,04 – 0,1	0,3 – 0,6

Class M1, M2, M3:

Cylindrical weights 1g - 10 kg: the surface shall be smooth and shall not appear to be porous.
Rectangular weights ≥ 5 kg: the surface shall be similar to that of cast iron carefully cast in fine sand mould. The surface may be painted or with any suitable coating.

6. Presentation and weight sequence

Weights of the same set shall be of the same class.
Fraction weights shall be contained in cases that have individual cavities.
The lid of the cases shall be marked to indicate their class in form of E1, E2, F1, F2, M1, M2, M3.

Class E1 - F2:

Individual weights and sets of weights shall be contained in cases made of wood, plastic or any suitable material that has individual cavities.

Class M1:

Individual or weights in sets ≤ 500 g shall be contained in a case with individual cavities.

The sequence of a weight set shall comprise of one of the following:
(1; 1; 2; 5) x 10^n kg
(1; 1; 1; 2; 5) x 10^n kg
(1; 2; 2; 5) x 10^n kg
(1; 1; 2; 2; 5) x 10^n kg
or
m x 1 x 10^n kg
m x 2 x 10^n kg
m x 5 x 10^n kg
where "n" represents a positive or negative integer or zero and where "m" represents the number of multiple pieces.

7. Marking

Except weights of class E1 and E2, weights of one gram and multiples of one gram shall be marked to clearly indicate their nominal value.
The numerals indicating the nominal values of the mass of the weight shall represent:

Kilograms - for masses 1 kg and above
Grams - for masses from 1 g to 500 g.

Duplicate or triplicate weights in a set shall be clearly distinguished **by a number** or **one or two asterisks** or **points** on the centre of the surface, except for wire weights which shall be distinguished by **one or two hooks**.

Class E1 and E2:

These weights shall not be marked with the nominal value, symbol of the unit or a sign for the class.
The user markings are only to separate the weights from other weights of class E1 and E2.
The class shall be indicated on the cover of the case.
Weights of class E2 may bear an off-centre point on the top surface to distinguish them from class E1.

Class F1 and F2:

Weights of class F1 and F2 shall bear, by burnishing or engraving, the indication of their **nominal value without any symbol of the unit.**
Weights of class F2 shall bear a **"F"** for their class identification additionally.

Class M1, M2 and M3:

Cylindrical and rectangular weights shall indicate the nominal value of the weight followed by the symbol "g" or "kg", in hollow or relief on the upper surface.
Class M1 shall bear the sign "M1" or "M" for the class identification.
Class M2 shall bear the sign "M2" for the class identification.
Class M3 shall bear the sign "M3" or "X" for the class identification.

Class M2 and M3 weights may bear the manufacturer mark.

User marking

Additionally to the marking of the nominal value, unit and the class identification weights can bear an user mark to provide exchanging with other weights of the same class.
The acceptable maximum values for user markings are given:

Class	Nominal value	Height of lettering (mm)	Maximum number of signs, numerals or letters
E1	≥ 1 g	2	3
E2	≥ 1 g	3	4
F1 to M2	1 g to 100 g	3	5
F1 to M2	200 g to 10 kg	5	5
F1 to M2	≥ 20 kg	7	5

Häfner is marking with a special laser, so the surface quality and mass stability is not affected by this kind of process. Also sheet weights <1 g are be able to be marked with this equipment.
Be careful: By other methods of marking (e.g. edging or burnishing) there is a danger of corrosion and alteration of the mass, especially by class E1 and E2.

8. Adjustment

A weight of given nominal value shall be adjusted in such a way that the conventional value of the result of weighing this weight in air is equal to the given nominal value, within the limits of the errors fixed for the accuracy class (see below table).
The conventional mass m_c shall be determined with an expanded measurement uncertainty U, where the coverage factor k=2 should be used.
The expanded uncertainty U, for k=2 of the conventional mass, shall be less than or equal to 1/3 of the maximum permissible error:

$$U\ (k=2) \leq 1/3\ \delta m$$

For each weight, the conventional mass m_c shall not differ by more than the difference of the maximum permissible error minus the expanded uncertainty, from the nominal value of the weight m_0:

$$m_0 - (\delta m - U) \leq mc \leq m_0 + (\delta m - U)$$

nominal value	class E1	class E2	class F1	class F2	class M1	class M2	class M3	nominal value
	+/- mg	+/- mg	+/- mg	+/- mg	+/- mg	+/- mg	+/- mg	
1 mg	0,003	0,006	0,020	0,06	0,20			1 mg
2 mg	0,003	0,006	0,020	0,06	0,20			2 mg
5 mg	0,003	0,006	0,020	0,06	0,20			5 mg
10 mg	0,003	0,008	0,025	0,08	0,25			10 mg
20 mg	0,003	0,010	0,03	0,10	0,3			20 mg
50 mg	0,004	0,012	0,04	0,12	0,4			50 mg
100 mg	0,005	0,016	0,05	0,16	0,5	1,6		100 mg
200 mg	0,006	0,020	0,06	0,20	0,6	2,0		200 mg
500 mg	0,008	0,025	0,08	0,25	0,8	2,5		500 mg
1 g	0,010	0,030	0,10	0,3	1,0	3	10	1 g
2 g	0,012	0,040	0,12	0,4	1,2	4	12	2 g
5 g	0,016	0,050	0,16	0,5	1,6	5	16	5 g
10 g	0,020	0,060	0,20	0,6	2,0	6	20	10 g
20 g	0,025	0,080	0,25	0,8	2,5	8	25	20 g
50 g	0,030	0,10	0,30	1,0	3,0	10	30	50 g
100 g	0,05	0,16	0,5	1,6	5	16	50	100 g
200 g	0,10	0,30	1,0	3,0	10	30	100	200 g
500 g	0,25	0,80	2,5	8,0	25	80	250	500 g
1 kg	0,5	1,6	5	15	50	160	500	1 kg
2 kg	1,0	3,0	10	30	100	300	1000	2 kg
5 kg	2,5	8,0	25	80	250	800	2500	5 kg
10 kg	5	16	50	160	500	1600	5000	10 kg
20 kg	10	30	100	300	1000	3000	10000	20 kg
50 kg	25	80	250	800	2500	8000	25000	50 kg
	+/- g	+/- g	+/- g	+/- g	+/- g	+/- g	+/- g	
100 kg		0,16	0,5	1,6	5	16	50	100 kg
200 kg		0,30	1,0	3,0	10	30	100	200 kg
500 kg		0,80	2,5	8,0	25	80	250	500 kg
1000 kg		1,6	5	16	50	160	500	1000 kg
2000 kg			10	30	100	300	1000	2000 kg
5000 kg			25	80	250	800	2500	5000 kg

Class E1 and E2:
The surface requirements (highly polished) shall be met at the whole weight surface after the adjustment process. There is no adjustment cavity allowed.
This weights shall be accompanied by certificates. The deviation from the nominal value **$mc - m_0$** shall be taken into account by the user.

Class F1 and F2:
Solid weights shall be met the required surface after the adjustment process.
Adjustment cavities are allowed. The weights shall be adjusted with the same material from which they are made or with tin, molybdenum or tungsten.

Class M1, M2 and M3:
The material used for adjusting shall be any solid material such as lead, it shall not change (chemically or electrolytically) the mass and constitution of the weight into which it is included.