English version

ULTIMHEAT® MUSEUM

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Technology of components used in heating.

Chapter 14

Technical introduction to fusibles links technology

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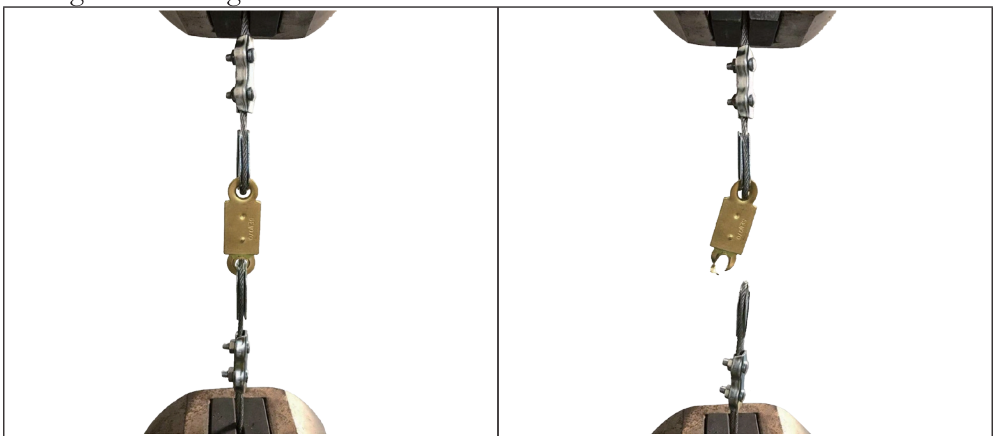
1 - Applicable standards

There is currently no international standard (ISO) or European standard (EN) specific to these components. However their test conditions have been defined in some standards for products using them, in particular:
-The old French standard of December 1990. NF S 61-937 of December 1990 Fire safety systems (S.S.I.) - Operated safety devices (D.A.S.)
- ISO10294-4 Fire resistance tests. Fire dampers for air distribution systems. Part 4: Test of thermal release mechanism
- ISO DIS 21925-1-2017 Fire resistance tests Fire dampers for air distribution systems Part 1: Mechanical dampers (Draft)
A number of foreign standards, with sometimes very different test procedures, exist but are not addressed in this document.

The most important is the American standard UL 33-2015 (Heat Responsive Links for Fire-Protection Service), whose ISO DIS 21925 standard draws some of its provisions.
It is also possible to quote:
- EN 60691: 2016 Thermal protectors - Requirements and application guide: This standard only applies to temperature limiting fuses used in electrical and electronic circuits, and does not apply to appliances with only a mechanical function.
- AS 1890-1999, Thermally released links (Australia)
- Hong Kong Standards Test laboratory, Instructions of Lam Chun Man §2.3.7

2 - Definition of the breaking load at ambient temperature also named maximum design load.

The breaking load, also known as the breaking strength of a fusible link, was a parameter of the old French standard NF S 61-937 of December 1990. It expressed resistance to longitudinal traction. It was up to the builder of the fuse link to determine a maximum load under which the fuse link did not open at the temperature of 20°C, whether by mechanical failure of the metal of the body, or by mechanical failure, creep or melting of the eutectic alloy. The standard gave no details on how to determine this value, nor the duration of the charge, but it was on the basis of one-third of this force that the temperature-rupture limit tests were conducted.
A similar notion is repeated in the UL33 standard, under the name of "maximum design load". at which the fuse links must withstand an ambient temperature of 70°F (21°C), for 150 hours, and 1/5 of that value is retained.
The European standards (ISO10294-4 and Iso Dis 2195-1-2017) which took over from the French standard NFS 61-937 have eliminated this notion of breaking strength and replaced it by the concept of faulty triggering.
However, the measurement of this value makes it possible, in particular for fusible links made of thin metals with low thermal inertia, to limit the stress to which they can be subjected to ambient temperature, independently of the measurement of the welded surface. It also makes it possible to check if the design tips used to limit tearing of the fixing holes are effective.



Measurement of the breaking load of a fusible link (Ultimheat Laboratory)

3 - Definition of the maximum force limit in use, and concept of faulty triggering(Faulty set-off)

Problems of false-tripping quickly appeared on links under permanent stress, because of the creep phenomena of fusible alloys, especially near their melting temperature. A rule of thumb, allowing a rough approximation of this value, is for fusible links with a flat welded surface, to use the value of this welded surface in mm² divided by 10 as the maximum use limit in decanewton (kg).
This value must then be corrected according to the mechanical resistance of the alloy (see correction table below).
From this table, it was possible, in the old French standard, to define the maximum force, and applying a reduction coefficient of 2/3, the maximum force limit of use. This standard, which did not refer to the melting temperatures of eutectic alloys, however, defined two classes: Class 1 fusible links, which should not open when subjected to this force for one hour at 60°C with an air velocity of 1m/s, and class 2 fusible links, where the temperature was raised to 90°C
The international standards (ISO10294-4 and Iso Dis 2195-1-2017) which took over from the French standard NFS 61-937 have eliminated this notion of breaking strength and replaced it by the concept of faulty triggering. The maximum operating limit force is replaced by the load applied under normal conditions of use, approaching UL33 in this way.
The temperature conditions for maintaining this charge are 60±2°C standard, with an air speed of 1m/s. Other temperatures such as 90°C are provided, and are linked of the maximum trigger temperature.
For example, for a fuse link with a maximum tripping value of 105°C (corresponding to the old Type 1 link definition), the fuse link will have to withstand a temperature of 60°C for one hour without tripping
For a maximum tripping value at 140°C (corresponding to the old Type 2 link definition), the fuse link will have to withstand a temperature of 90°C for one hour without tripping.
This test is part of the standard tests carried out by statistical sampling in production.

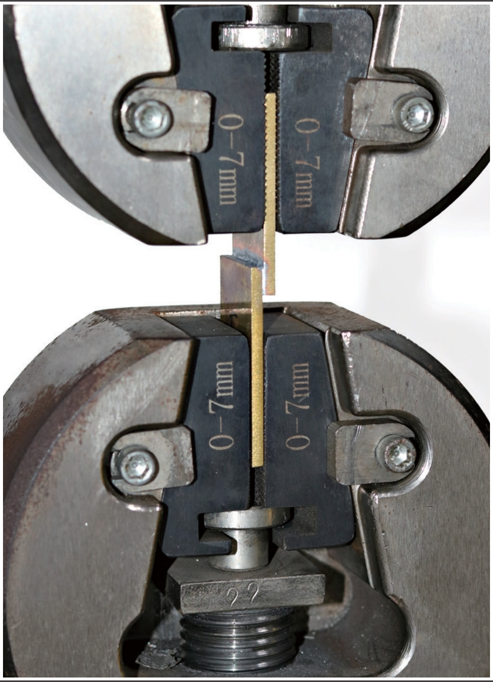
4 - Solder tensile strength testing in production

One faulty triggering parameter, which has not been described in the standards, is the "Cold Joint". However, it is the one who is responsible for the largest number of false triggers after installation. It is characterized by a weld that does not cover the entire weld surface, or where the solder did not melt completely. Cold joints are unreliable. The solder bond will be poor This defect is mostly invisible.
To eliminate this risk, the fuse links are 100% tested at the end of production, automatically applying a load calculated according to the weld surface.

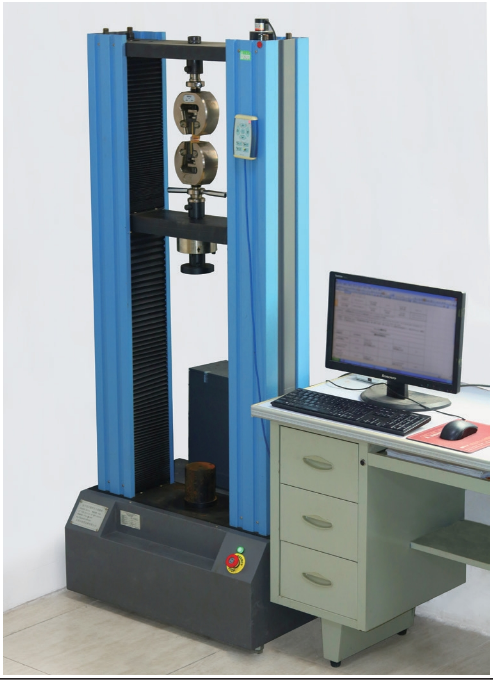
Automated testing of the solder strength in production at ambient temperature

5 - Measurement and verification of the mechanical strength of the alloy

The ultimate tensile strength of Rohs and non-Rohs eutectic alloys greatly affects the mechanical strength of welds. In order to verify under conditions close to their use, respecting the cleaning procedure of the surfaces and the quality of the soldering flux used, a test procedure on specimens, using an amount of alloy always identical to +/- 0.1gr, and a calibrated weld thickness was developed. This IQC process is used to validate each delivery of eutectic alloy.



Specimen during test



Testing equipment in our laboratory

6 - Measurement of alloy melting temperature

The melting temperature of the alloy (or explosion of the thermal glass bulb), is a critical parameter in the design of a fire safety mechanism. Its checking is not requested in the standards ISO10294-4, Iso Dis 2195-1-2017 and NFS 61-937, nor in the UL33 standard.

This is likely due to the difficulty of this measurement.

In order to provide reproducible and reliable measurement values, we have developed our own method for the validation of eutectic alloys and thermal glass bulbs, particularly suitable for normal use of these components.

In this test procedure for receiving alloys, carried out in our laboratory, 10 fusible link specimens, of a special model, are welded 24 hours before the test, and soldered with the alloy to be checked, are placed in a stirred liquid* bath **, and subject to a load of 4N. The temperature is then raised at a rate of 0.5°C per minute from 17°C (30°F) below the liquidus temperature of the alloy. The opening temperatures are recorded in 10 individual tests and their unit values are compared to the specifications of the alloy used. The average trigger value is used as the reference value of the melting point, and the average deviation x 2 is used as tolerance limit.

For the verification of the glass bulbs, 10 samples of these are individually mounted in suitable supports, subjected to a load of 10N and tested under the same temperature conditions as the fuse links.

The acceptability limits on the reference value of the melting point of the alloy or the explosion of the glass bulb to which the reference tolerance is applied are -7% / + 10% in °C of the temperature liquidus of the alloy given the specifications of it, or the nominal temperature of the glass bulb. If necessary, the measured values can then be classified in the levels defined by the different standards.

*: the liquid is water for temperatures from 20 to 90°C, and the oil with a flash point higher than the maximum temperature of the test is used for higher temperatures.

**: The measurement of the bath temperature is taken at 4 separate locations by 4 calibrated Pt100 class A probes, located at the same level as the fuse and at less than 50mm distance, are used to validate its homogeneity around the trigger being tested. The concordance at ± 0.2°C between the 4 values is required to start the tests.

		
Special fusible links specimens for fusing temperature test of the alloy, before and after melting		**Automatic equipment for controlling the melting temperature of eutectic alloys in our laboratory**

7 - Minimum operating force

The minimum operating force is a critical parameter in the design of a fire safety mechanism. The design of certain fusible links or thermal triggers, in particular with ramps, joints or bosses, may lead to the risk of non-opening due to the friction forces. Its verification is not provided in the ISO10294-4, Iso Dis 2195-1-2017 and NFS 61-937 standards. The UL33 standard has defined a number of discontinuous ranges of temperature, and how to check the operation of the link under minimum loads. This measurement is performed in a stirred liquid bath, with a temperature rise rate of 0.5°C (1°F) per minute. The minimum load is provided by the manufacturer, but cannot be less than 4N. The trip must occur during warm-up, while the temperature of the liquid bath is less than 11°C (20°F) above the minimum value of the temperature class used. This value is raised to 17°C (30°F) for temperature classes of 163°C (325°F) and above.
The testing of these parameters in our laboratory was inspired by the UL33, but adapted to each alloy and no longer to a discontinuous range.
The thermal links (glass bulb or eutectic alloy) are placed, in the 24 hours after their welding, in a stirred liquid bath and subjected to the weakest force to which they can be subjected in normal operation, and at least to 4N. The temperature is then raised at a rate of 0.5°C per minute from 17°C (30°F) below the solidus temperature of the alloy, or the nominal temperature of the glass bulb. The tolerances of acceptability limits are a trigger of -7% and+ 10% in °C of the liquidus temperature of the alloy, or the nominal temperature of the glass bulb.

Temperature classifications upon UL33 (informative)

Temperature class name	Maximum and minimum values of the temperature class (°C, °F)	Minimum triggering temperatures under the minimum load (°C, °F)
Low	51-54°C (125-130°F)	< 62°C, (< 145°F)
Ordinary	57-77°C (135-170°F)	< 68°C, (< 155°F)
Intermediate	79-107°C (175-225°F)	< 90°C, (< 195°F)
High	121-149°C (250-300°F)	< 132°C, (<270°F)
Extra high	163-191°C (325-375°F)	< 180°C, (<355 °F)
Very extra high	204-246°C (400-475°F)	<221°C, (<430 °F)
Ultra high	260-302°C (500-575°F)	<277°C, (<605 °F)

		
Typical assembly of a thermal glass bulb device to check its minimum trip threshold (view out of test tank)	Typical assembly of a fusible link to check its minimum trip threshold (view out of test tank)	Automatic control equipment for checking the minimum force of thermal links in our laboratory

8 - Threshold response time limit.

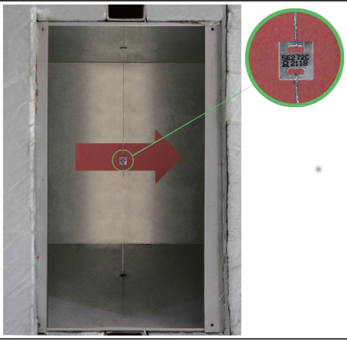
On this type of measurement, French, ISO and UL33 standards have completely different approaches.
The ISO and French standards measure the response time at a temperature rise rate of 20°C per minute for a fixed maximum duration, which is supposed to represent the temperature rise during a fire, while the UL33 standard measures the time triggering an instantaneous variation in temperature, a variable temperature step according to the classes of triggers, similar to what is done to define the response times of the temperature sensors.
Both methods give completely different trigger times, and in order to be able to classify the large variations that exist between products, the UL33 standard has been obliged to define devices with a fast response time, a standard reaction time and those equipped with a protective coating against corrosion.

Test equipment, allowing:
- Measurement of the triggering time of eutectic alloy links or thermo-frangible bulb during a normalized fast temperature rise at 20°C per minute, starting from a plateau at 20 or 25°C, according to NFS 61-937, ISO 10294-4, and ISO DIS 2195-1
- The mechanical resistance test at constant temperature for one hour, according to NFS 61-937, ISO 10294-4, and ISO DIS 2195-1
- It works with loads from 5 to 320 DaN.

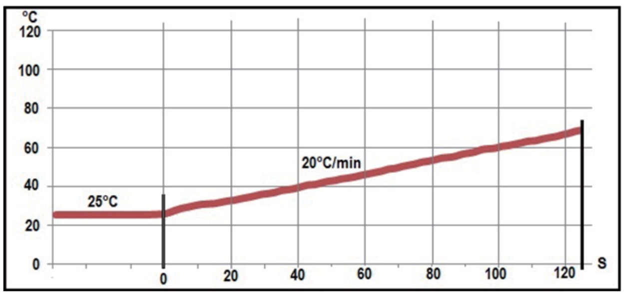
Test equipment allowing:
- The measurement of the response time at an instantaneous temperature step according to UL33-11-2. The temperature steps are a function of the thermal links temperature classes. The most common are:
24 ± 1°C and 135 ± 1°C (72 ± °F and 275°F ± 2°F)
24 ± 1°C and 197 ± 1°C (72 ± °F and 386°F ± 2°F)
- The mechanical resistance test at constant temperature for 90 days according to UL33-12.
- It works with loads from 5 to 320 DaN.

9 - Threshold temperature limit

This value should not be confused with the melting temperature of the alloy (or rupture of the bulb), because this trigger value involves the parameter "thermal response time".
The standards agree on the rate of rise in temperature when measuring the tripping time. The threshold temperature limit is the temperature at which the thermal link must have tripped when subjected to a fast temperature rise of 20°C ± 2°C per minute, starting at an ambient temperature of 25°C ± 2°C . (NB: this ambient temperature was defined at 20°C in the old standard NF S 61-937).
ISO 10294-4 allows the definition of different trigger limit values such as 50°C, 105°C, 120°C, 180°C, 350°C or others depending on the specificities of the device.
According to ISO DIS 2195-1-2017, it is up to the manufacturer of the fuse link to determine this value.



Position of the thermal links or thermal bulbs mechanisms in the air stream for threshold temperature limit measurement



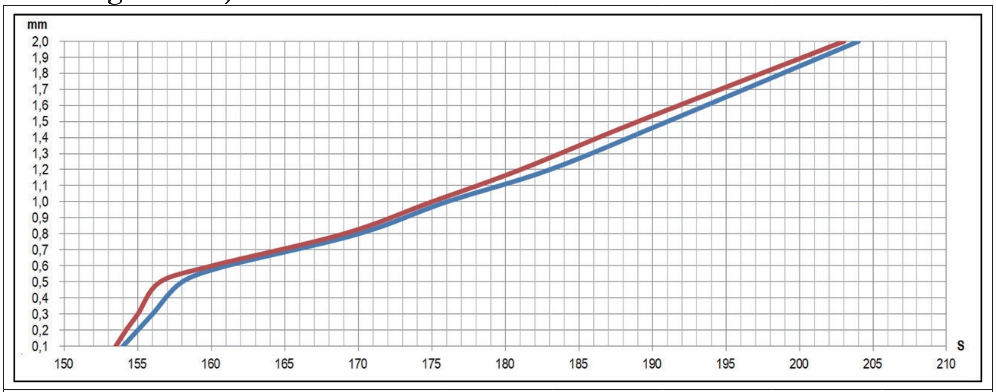
Example chart of temperature rise at 20°C per minute, starting from a plateau at 25°C

10 - Influence of the material and its thickness on the response time

The response time of a thermal link to a rise in temperature depends of course on the melting temperature of the alloy used, but also on the thermal inertia of the link, itself a function of the thermal conductivity of its constituents, and the ratio between its surface and its thickness. A good balance must be found between the mechanical strength at break (the link becomes more and more fragile when its thickness decreases) and its response time increases with thickness.
In order to quantify these effects, we realized response time measurements in

different thicknesses of links of the same model, using the same fusible alloy.

Average threshold response time and threshold temperature on one single model of fusible link, soldered with non-Rohs eutectic alloy at 72°C, for various thicknesses. (Tests made on a 15x42mm fusible link, in brass (in blue) and in copper (in red), with thicknesses of 0.1mm to 2mm, and 225mm^2 soldering surface).



Average threshold response time and threshold temperature on the full range of existing models against thickness, soldered with non-Rohs eutectic alloy at 72°C

Metal thickness (mm)	0.3	0.5	0.6	0.8	1	1.2	1.5
Threshold time	2min 50s	3min 3s	3min 6s	3min 10s	3min 15s	3min 32s	3min 39s
Threshold temper-ature*	81.7	86	87	88	90	95.7	98

* The triggering temperature, measured by two thermocouples of very low thermal inertia, located near the link in the air duct is the result of several concomitant parameters: the thermal inertia of the link, the reduction of the mechanical resistance of the link alloy near the melting point, and the load applied to the link. In the hundreds of tests used for these measurements, the load is the maximum load given in the table in Appendix 1, depending on the weld surface. The test method and equipment comply with ISO10294-4.and ISO DIS 21925-1 2017, fig. C1.

11-Reliability tests after corrosion

Previously, the corrosion resistance tests for metal parts in the old NF S 61-937 standard of December 1990 referred to chapter 4 of the basic text of standard NF P 24-351 concerning surface protection in buildings.
In the ISO10294-4-2001 standard, specific corrosion resistance tests were introduced as an option. In the new ISO DIS 2195-1-2017 standard being consulted, these tests, identical to those of ISO10294-4, are no longer optional but mandatory, thus approximating the UL33 tests.
These tests consist in submitting batches of 5 samples of links to tests of resistance to different atmospheres, supposed to represent the different types of atmospheric pollution:
- Salt spray test with 20% sodium chloride for 120 hours at 35°C (5 days) Important note: the sodium chloride concentration of this test is 400% higher than the standard salt spray tests at Neutral PH (NSS) given in the classical ISO 9227 standard.
- A test of resistance to a mixture of moist air and hydrogen sulphide (H_2S) at 10,000 PPM *, at an unspecified room temperature during 5 days **
- A test of resistance to a mixture of moist air, carbon dioxide (CO_2) at 10,000 PPM and sulfur dioxide (SO_2) at 10,000 PPM *, at an unspecified room temperature during5 days **
After having been subjected to these three different environmental conditions, the samples of each batch are again tested in response time and in load-bearing capacity.
* Hydrogen sulphide and sulfur dioxide are toxic gases, and hydrogen sulphide is flammable.
**Caution: UL33 standards give standard test times of 10 days instead of 5 days and

also provide a test period of 30 days for links intended for corrosive environments. In view of the severity of the UL corrosion resistance tests, this standard also provides that the links may be additionally protected by wax, lead, teflon, polyester or other. This protective layer must then withstand the Faulty set-off test.

Note on accelerated tests of resistance in air with a high concentration of hydrogen sulphide (H^2S). Concentration of 1% (10,000 Ppm).

1 / - The temperature is not indicated in the draft ISO standard, but these tests having been copied from the UL33 standard, the latter specifies: 75 ± 5°F (24 ± 3°C).

2 / - These tests are similar to those prescribed by the environmental standard EN 60068-2-43-2003 (Kd tests), intended to verify the behavior of silver parts of electrical contacts and silver-plated metals, with a concentration in H^2S of 10 to 15 ppm.

It is important to note the standards UL33, ISO10294 and ISO DIS 21925 give a concentration in H^2S 1000 times higher.

In the particular case of alloys used in fusible links, it is found that the hydrogen sulphide reacts with copper and copper and zinc alloys to form copper sulphide (CuS). The reaction rate depends on the composition.

Wet hydrogen sulphide corrodes little alloys with more than 20% zinc such as C26000 (CuZn30) with 70 % copper; C28000 (CuZn40) with 60% copper, and C44300 called "Admiralty brass" (70% copper and low percentage of arsenic and tin) for which the rate of corrosion is limited to 50 to 75 microns / year.

For cuprous alloys containing less than 20% zinc, such as C11000 (99.9% electrolytic copper) and C23000 (CuZn15) at 85% copper, this corrosion rate reaches 1250 to 1625 microns per year (1.2 to 1.6mm / year).

Tin is little attacked below 100°C, but above this temperature forms tin sulphide (SnS).

Zinc is not very sensitive to hydrogen sulphide corrosion because an insoluble layer of zinc sulphide (ZnS) is formed.

		
Test equipment to salt spray in our laboratory	Copper, brass, and coated fusible links after 300h salt spray at 20%	Zinc plated steel fire detection mechanism after 240h salt spray at 20%

Annex 1

Relation between weld surface and maximum load*

The following formula can be used as the first estimate of the maximum load of a fusible link:

L = S / 10

with L = maximal force of use in DaN, for a non-Rohs eutectic alloy at 72°C, and S = average surface of the weld in mm^2.

In this formula, the maximum force limit of use is that defined by the test of 1h at 60°C. It is possible to slightly increase this maximum use limit by adding bosses or separation ramps.

Corrections must be made according to the alloy used (see annex 2) and the standard to be complied with. In particular, after correction according to the alloy, these values must be divided by 5 to meet the UL33 standard.

Specific tests by fuse model and tripping temperature are available on request.

* The threshold temperature limit depends on alloy composition and ambient temperature. Values are given for guidance only, and for a 72°C non ROHS alloy. Alloys with temperatures below 72°C and those that are ROHS compliants, generally have a high proportion of Indium, which greatly reduces the mechanical strength.

Annex 2

Correction coefficients to be applied to the maximum permissible loads according to the most usual eutectic alloys used ***

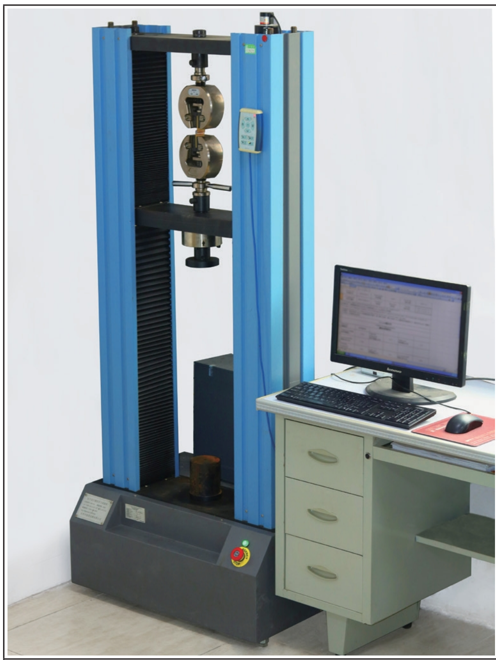
Alloy type	Non-Rohs alloys, with Lead and /or Cadmium and with Indium or Gallium				Non-Rohs alloys, with Lead and /or Cadmium but without Indium or Gallium						Rohs alloy
Melting temperature	47°C (117°F) 19 % Indium	57°C (135°F) 21% Indium	65-66°C (149-151°F) 1,4% Gallium	68°C (155°F) 25% Indium	72°C (162°F)	96°C (205°F)	103°C (218°F)	120°C (248°F)	140°C (284°F)	182°C (360°F)	72°C (162°F) 66% Indium
Correction ratio versus non-Rohs 72°C alloy	0.41	0.39	0.76	0.31	1	0.77	1.65	0.9	1.45	1.78	0.65

*** According to comparative tests carried out on specimens with a welding surface of 225mm², tests carried out at ambient temperature, at a tensile strength test speed of 0.5mm/min.

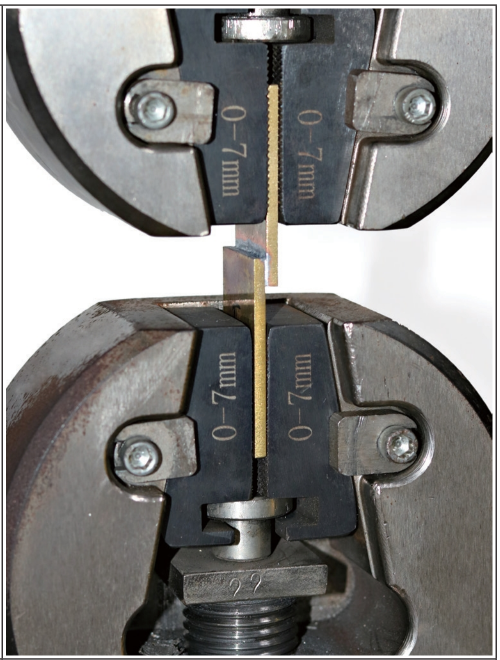
Annex 3

Examples of changes of ultimate tensile strength and elongation at break of eutectic alloys in 30 days (Compared with the same alloy).

Type d'alliage	Alliages non ROHS, comportant du plomb et/ou du cadmium et avec indium ou gallium)				Alliages non ROHS, comportant du plomb et/ou du cadmium mais sans indium ou gallium						Alliage ROHS
Température de fusion	47°C (117°F) 19 % Indium	57°C (135°F) 21% Indium	65-66°C (149-151°F) 1,4% Gallium	68°C (155°F) 25% Indium	72°C (162°F)	96°C (205°F)	103°C (218°F)	120°C (248°F)	140°C (284°F)	182°C (360°F)	72°C (162°F) 66% Indium
Variation de résistance mécanique après 30 jours	79%	104%	102%	148%	70%	102%	106%	97%	129%	87%	48%



Tensile strength and elongation at break equipment

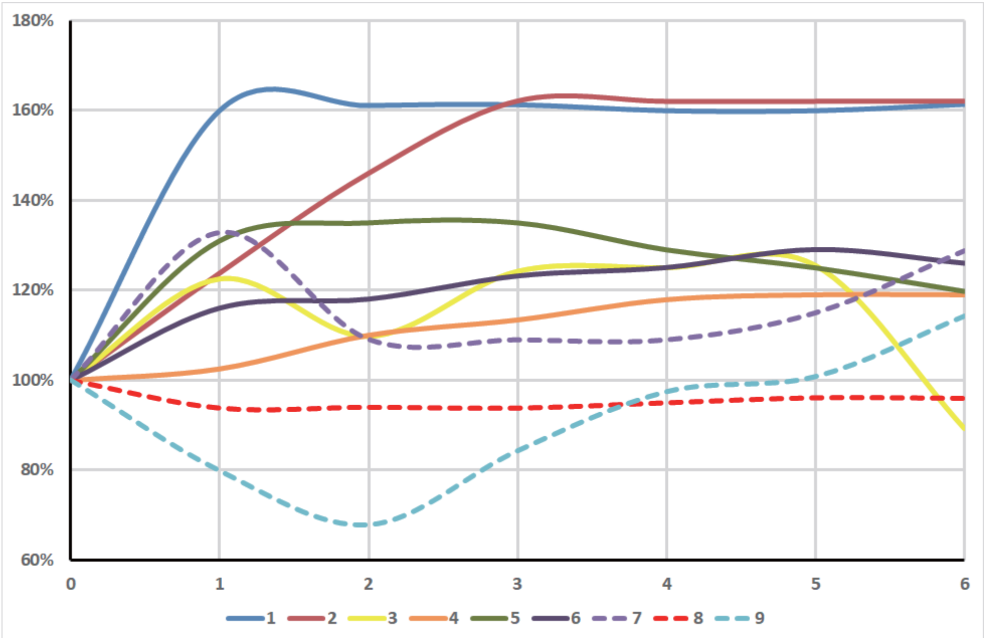


Specimens tested upon the weld ultimate tensile strength. Values measured in our own testing equipment at a 0.05mm/min speed

Annex 4

Change in ultimate tensile strength and creeping of quaternary eutectic fusible alloys versus time

The quaternary alloys (Pb, Sn, Bi, Cd) undergo a change in their mechanical strength and their elongation rate for a long time after their melting. This is due to a slow reorganization of the crystallization. In 42 days (6 weeks), the breaking strength can vary up to tenths of percent.



1: Alloy at 47°C
2: Alloy at 57°C
3: Alloy at 70-72°C (Rohs)
4: Alloy at 70-72°C (Non Rohs)
5: Alloy at 92°C
6: Alloy at 96°C
7: Alloy at 125°C
8: Alloy at 103°C
9: Alloy at 140°C

The above curve represents the variation of the resistance, in % of the value measured immediately after soldering, over 6 weeks, of welded test specimens, using a 225mm² surface weld, made with various fusible alloys.
Values measured in our own test equipment at a slow pulling speed of 0.05mm/min.