# IEC 62047-25

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## Semiconductor devices – Micro-electromechanical devices – Part 25: Silicon based MEMS fabrication technology – Measurement method of pull-press and shearing strength of micro bonding area

## Dispositifs à semiconducteurs – Dispositifs microélectromécaniques – Partie 25: Technologie de fabrication de MEMS à base de silicium – Méthode de mesure de la résistance à la traction-compression et au cisaillement d'une micro zone de brasure

IEC 62047-25:2016-08(en-fr)

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Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
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CONTENTS

FOREWORD....4
1 Scope....6
2 Normative references....6
3 Terms and definitions....6
4 Requirements....7
4.1 Testing structure design requirements....7
4.2 Testing structure fabrication requirements....9
4.3 Testing environment requirements....9
5 Testing method....9
5.1 General....9
5.2 Pull-press testing method....9
5.2.1 Imposing the loading force....9
5.2.2 Pull-press testing method operation process....9
5.2.3 Pull-press testing method result process....10
5.3 Shearing testing method....10
5.3.1 Shearing testing method operation process....10
5.3.2 Shearing testing method result process....12
Annex A (informative) Dimensions for testing structure and tensile/compressive strength....13
A.1 Dimensions for testing structure....13
A.2 Tensile strength and compressive strength....13
Annex B (informative) Pull-press testing method example....21
B.1 Dimensions for testing structure....21
B.2 Tensile strength and compressive strength....21

Figure 1 – Pull-press testing structure....7
Figure 2 – Shearing testing structure....8
Figure 3 – Pull-press testing method operation process....10
Figure 4 – Shearing testing method operation process....11

Table 1 – Dimensions for shearing testing structure....12
Table A.1 – Dimensions for testing structure....13
Table A.2 – Tensile strength and compressive strength (bonding area: 10 μm × 10 μm)....13
Table A.3 – Tensile strength and compressive strength (bonding area: 20 μm × 20 μm)....14
Table A.4 – Tensile strength and compressive strength (bonding area: 30 μm × 30 μm)....14
Table A.5 – Tensile strength and compressive strength (bonding area: 40 μm × 40 μm)....15
Table A.6 – Tensile strength and compressive strength (bonding area: 50 μm × 50 μm)....15
Table A.7 – Tensile strength and compressive strength (bonding area: 60 μm × 60 μm)....15
Table A.8 – Tensile strength and compressive strength (bonding area: 70 μm × 70 μm)....16
Table A.9 – Tensile strength and compressive strength (bonding area: 80 μm × 80 μm)....16
Table A.10 – Tensile strength and compressive strength (bonding area: 90 μm × 90 μm)....17
Table A.11 – Tensile strength and compressive strength (bonding area: 100 μm × 100 μm)....17

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Table A.12 – Tensile strength and compressive strength (bonding area: 110 μm × 110 μm) ..... 18
Table A.13 – Tensile strength and compressive strength (bonding area: 120 μm × 120 μm) ..... 18
Table A.14 – Tensile strength and compressive strength (bonding area: 130 μm × 130 μm) ..... 19
Table A.15 – Tensile strength and compressive strength (bonding area: 140 μm × 140 μm) ..... 19
Table A.16 – Tensile strength and compressive strength (bonding area: 150 μm × 150 μm) ..... 20
Table B.1 – Dimensions for testing structure ..... 21
Table B.2 – Tensile strength and compressive strength (bonding area: 110 μm × 110 μm) ..... 21

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## Part 25: Silicon based MEMS fabrication technology – Measurement method of pull-press and shearing strength of micro bonding area

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The text of this standard is based on the following documents:

| FDIS | Report on voting |
|---|---|
| 47F/249/FDIS | 47F/252/RVD |

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# SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

## Part 25: Silicon based MEMS fabrication technology – Measurement method of pull-press and shearing strength of micro bonding area

## 1 Scope

This part of IEC 62047 specifies the in-situ testing method to measure the bonding strength of micro bonding area which is fabricated by micromachining technologies used in silicon-based micro-electromechanical system (MEMS).

This document is applicable to the in-situ pull-press and shearing strength measurement of the micro bonding area fabricated by microelectronic technology process and other micromachining technology.

Micro anchor, fixed on the substrate through the micro bonding area, provides mechanical support of the movable sensing/actuating functional components in MEMS devices. With the devices scaling, the bonding strength degradation, induced by defects, contaminations and thermal mismatch stress on bonding surface, becomes severer. This standard specifies an in-situ testing method of the pull-press and shearing strength based on a patterned technique. This document does not need intricate instruments (such as scanning probe microscopy and nanoindenter) and to prepare the test specimen specially.

Since the testing structure in this standard can be implanted in device fabrication as a standard detection pattern, this document can provide a bridge, by which the fabrication foundry can give some quantitative reference for the designer.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62047-1, *Semiconductor devices – Micro-electromechanical devices – Part 1: Terms and definitions*

ISO 10012, *Measurement management systems – Requirements for measurement processes and measuring equipment*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62047-1 and ISO 10012 and the following apply.

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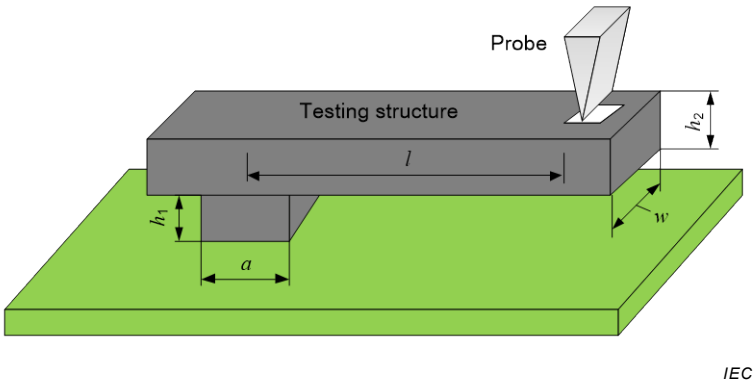
**3.1**
**anchor**
silicon-glass bonding area which supports the MEMS function structure

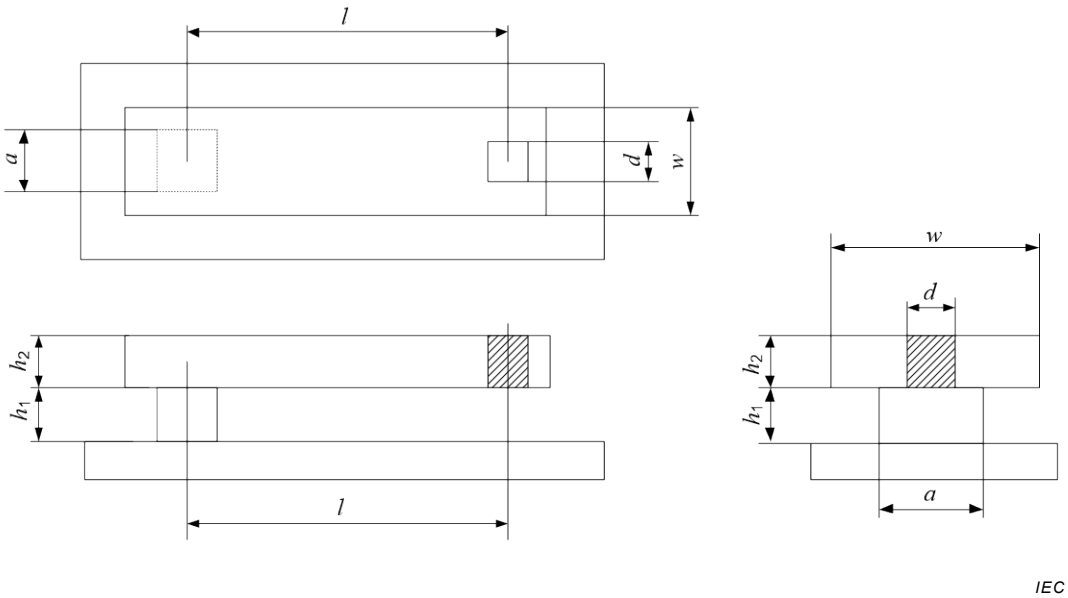
## 4 Requirements

### 4.1 Testing structure design requirements

The schemes of testing structures are shown in Figure 1 and Figure 2.




**a) The scheme of the pull-press testing structure**




**b) The three-view drawing of the pull-press testing structure**

**Key**

$h_2$ thickness of the testing structure arm

$h_1$ height of the anchor beam in the bonding area

$a$ side length of the bonding area

$l$ length of the testing structure arm, this parameter should be designed with sequential values

$w$ width of the testing structure arm

$d$ dimension of the loading point

**Figure 1 – Pull-press testing structure**

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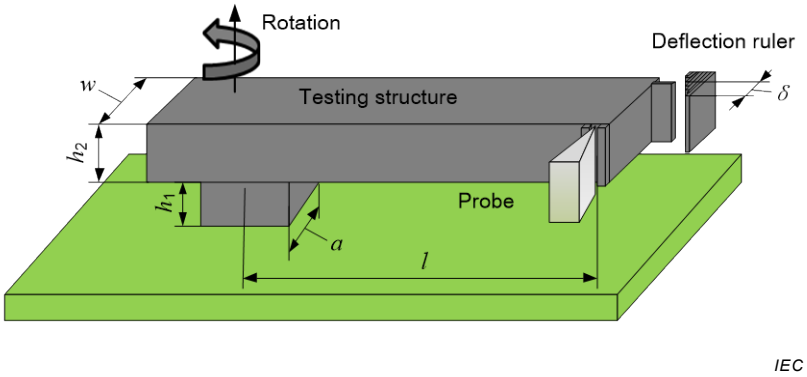
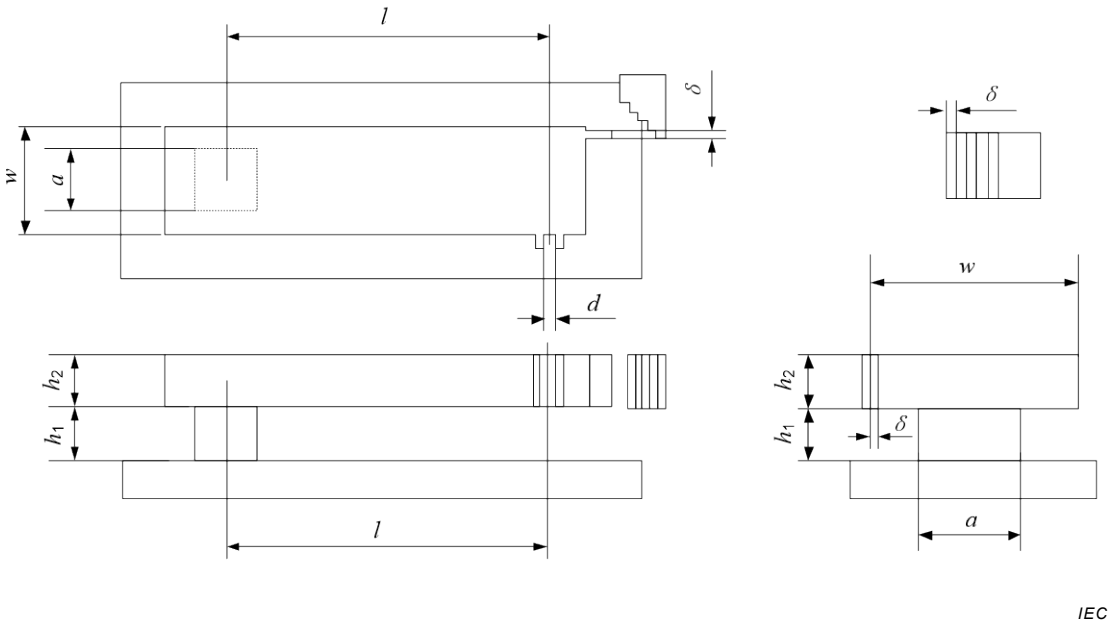



**a) The scheme of the shearing testing structure**




**b) The three-view drawing of the shearing testing structure**

**Key**

| | |
|---|---|
| $h_2$ | thickness of the testing structure arm |
| $h_1$ | height of the anchor beam in the bonding area |
| $a$ | side length of the bonding area |
| $l$ | length of the testing structure arm |
| $w$ | width of the testing structure arm |
| $d$ | dimension of the loading point |
| $\delta$ | resolution of the rotation ruler |

**Figure 2 – Shearing testing structure**

The design of the testing structure should be as follows:

a) To prevent the testing structure arm from breaking earlier than the bonding area, the strength of the arm should be designed high enough. For instance, if the arm thickness is limited by design rule, a wider arm design is recommended.

b) The arm length of pull-press strength testing structure should be designed with sequential values. The common difference, the length interval, should satisfy the requirement of the testing resolution. The consumed area by the testing structure should be also taken into consideration.

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c) The design of the ruler within the shearing strength testing structure should satisfy the resolution requirement. The ruler should be clearly monitored by the optical microscopy.

d) The testing structure should be designed to be robust enough to withstand the dimension deviation induced by fabrication process. The roughness of the structure surface caused by the wet or dry etching process, isotropic or anisotropic etching process should be also taken in consideration in design work.

### 4.2 Testing structure fabrication requirements

Requirements for bulk silicon testing structures with micro bonding area(s) are the following:

a) The fabrication of testing structures should meet the requirements of bulk silicon processes.

b) The testing structure material is bulk silicon, so the physical and chemical characteristics should refer to the silicon wafer used in the practical fabrication processes.

c) It is highly recommended to use RIE process to etch the anchor of the testing structure to ensure the anchor formation.

In case of strength testing of micro bonding area other than silicon based MEMS, similar structures may be prepared by using different materials, and other requirements shall be proposed.

### 4.3 Testing environment requirements

Testing environment requirements are the following:

a) A kind of violent air flow is prohibited during the testing operation. The testing bench should be stabilized.

b) Environmental contaminations caused by the dusts and fragments from the fracture of the testing structure should be taken into consideration in testing operation processes.

## 5 Testing method

### 5.1 General

During the testing operation process, the testing structure is placed on the probe station. The deformation or fracture of the structure is monitored by microscopy and the bonding strength can be calculated utilizing the testing structure parameters.

### 5.2 Pull-press testing method

#### 5.2.1 Imposing the loading force

During the testing operation with pull-press testing method, the loading force is imposed vertically at the loading point on the structure arm.

#### 5.2.2 Pull-press testing method operation process

The pull-press testing method operation process is as follows:

a) During the operation process, the chip with testing structure is fixed on the probe station. The loading force is imposed vertically at the loading point on the structure arm by the station needle (A) until the arm is deformed to contact with the bottom surface and the bonding area (B or C) is monitored by the microscopy, see Figure 3. The bonding strength is defined to be higher than $\sigma_{li,T}$ (or $\sigma_{li,C}$) while the fracture occurs in the structure with arm length of $l_{i+1}$ ($l_i > l_{i+1}$) and does not occur in the structure with arm length of $l_i$, where $\sigma_{li,T}$ and $\sigma_{li,C}$ are tensile strength and compressive strength respectively, namely the maximum stress value at the bonding area when the corresponding testing structure arm deforms to contact with the bottom surface, acquired by finite element analysis. And subscript T and subscript C represent tensile and compressive stress respectively.

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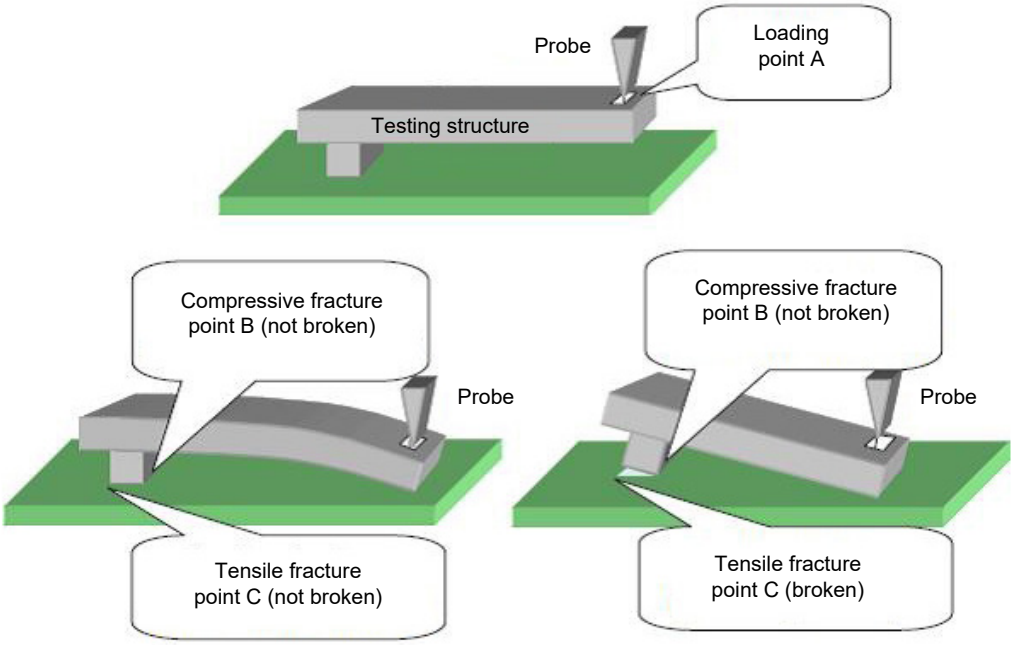


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**Figure 3 – Pull-press testing method operation process**

b) The loading should be perpendicular to the bottom surface and the loading process should be slow and stable. The needle and whole testing structure should be present in the field of views under an optical microscopy. When the arm contacts with the bottom surface (or the fracture occurs in the testing structure), the loading process should be stopped and the needle should be raised slowly until it is separated from the testing structure.

### 5.2.3 Pull-press testing method result process

During the testing structure arm design process, a table, about the maximum compressive and tensile stress value at the bonding area when every testing structure arm in the design deforms to contact with the bottom surface, should be built. After the testing operation, the bonding strength can be referred to the table according to the arm length with which the anchor is broken.

In case that the stress cannot be obtained, the testing structure parameters in Annex A can be used. And the reference stress tables are listed from Table A.2 to Table A.16.

If the arm length is not listed in the reference tables, the relative stress can be interpolated from the table content.

If the fracture occurs in the bulk silicon structure first, the bonding strength can be known as bigger than the bulk silicon strength.

## 5.3 Shearing testing method

### 5.3.1 Shearing testing method operation process

The shearing testing method operation process is as follows:

a) During the operation process, the chip with testing structure is fixed on the probe station. The loading force is imposed laterally at the loading point on the structure arm by the station needle (A) and the deformation is monitored by the microscopy, see Figure 4. The rotation deflection can be read out from the ruler located at the end of the arm.

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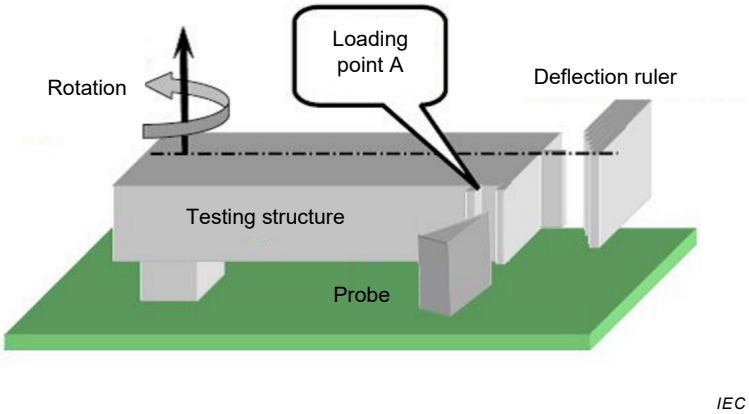
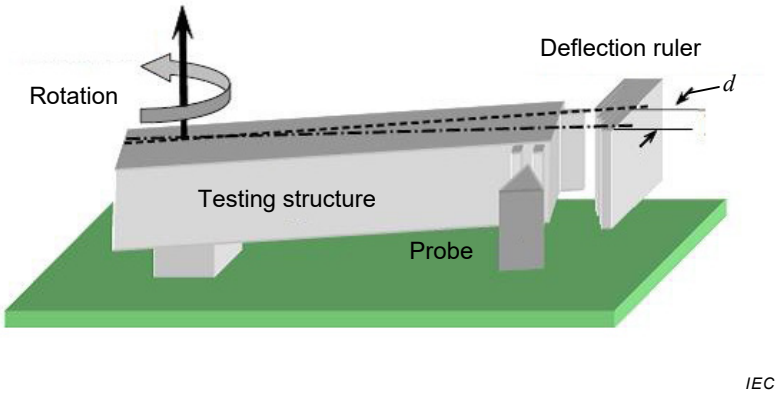



**a) Before probe loading**




**b) Dimension of the rotation deflection at a monitoring length by the deflection ruler**

**Figure 4 – Shearing testing method operation process**

b) The loading should be parallel with the bottom surface and the loading process should be slow and stable. The needle and whole testing structure should be present in the field of views under the optical microscopy. When the fracture occurs in the testing structure or at the bonding area, the loading process should be stopped and the needle should be retracted slowly until it is separated with the testing structure.

c) According to various bonding areas, the recommended testing structure dimensions are calculated in order to get a reasonable resolution and operation needle pressure, as listed in Table 1.

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**Table 1 – Dimensions for shearing testing structure**

| $a \times a$ (μm$^2$) | $w \times h_2$ (μm$^2$) | $l$ (μm) |
|---|---|---|
| 13 × 13 | 33 × 80 | 243 |
| 17 × 17 | 37 × 80 | 241 |
| 20 × 20 | 40 × 80 | 240 |
| 25 × 25 | 45 × 80 | 238 |
| 30 × 30 | 50 × 80 | 240 |
| 40 × 40 | 100 × 80 | 565 |
| 50 × 50 | 150 × 80 | 607 |
| 60 × 60 | 200 × 80 | 596 |
| 70 × 70 | 250 × 80 | 605 |
| 80 × 80 | 250 × 80 | 614 |
| 90 × 90 | 300 × 80 | 1 456 |
| 100 × 100 | 400 × 80 | 1 423 |
| 110 × 110 | 400 × 80 | 1 444 |
| 120 × 120 | 400 × 80 | 1 449 |

### 5.3.2 Shearing testing method result process

The shearing stress $\tau_{\max}$ can be calculated as:

$$\tau_{\max} = 0{,}14 \times \frac{h_2 w^3}{a^3 l^2} d$$

where

$h_2$ thickness of the testing structure arm

$a$ side length of the bonding area

$l$ length of the testing structure arm

$w$ width of the testing structure arm

$d$ rotation deflection

If the fracture occurs in the bulk silicon structure first, the bonding strength can be known as bigger than the bulk silicon strength.

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# Annex A
(informative)

# Dimensions for testing structure and tensile/compressive strength

## A.1 Dimensions for testing structure

Ranges of dimensions for testing structure are described as Table A.1.

**Table A.1 – Dimensions for testing structure**

*Dimensions in μm*

| $l$ | $a$ | $h_2$ | $w$ | $h_1$ | $d$ |
|---|---|---|---|---|---|
| 300 to 2 000 | 10 to 150 | 20 (a <= 70)<br>70 (a > 70) | 200 | 80 (a <= 70)<br>80 (a > 70) | 100 |

## A.2 Tensile strength and compressive strength

Tensile strength $\sigma_{L,T}$ and compressive strength $\sigma_{L,C}$ are described in the following tables, from Table A.2 to Table A.16.

**Table A.2 – Tensile strength and compressive strength (bonding area: 10 μm × 10 μm)**

| $l$ (μm) | $\sigma_{L,T}$ (MPa) | $\sigma_{L,C}$ (MPa) |
|---|---|---|
| 800 | 1 072,1 | -1 135,8 |
| 850 | 1 008,3 | -1 067,9 |
| 900 | 951,6 | -1 007,6 |
| 950 | 900,7 | -953,5 |
| 1 000 | 855,1 | -905,0 |
| 1 050 | 813,7 | -861,0 |
| 1 100 | 776,0 | -821,0 |
| 1 150 | 741,6 | -784,4 |
| 1 200 | 710,0 | -750,9 |
| 1 250 | 680,9 | -720,0 |
| 1 300 | 654,2 | -691,7 |
| 1 350 | 629,3 | -665,3 |
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