Calculation of hybrid joints used in modern aerospace structures

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Abstract: *The state – of - the art of aeronautical structures show that parts are manufactured and subsequently assembled with the use of fasteners and/ or bonding. Adhesive bonding is a key technology to low weight, high fatigue resistance, robustness and an attractive design for cost structures.*
The paper results resolve significant problems for two groups of end-users:
1) for the aerospace design office: a robust procedure for the design of the hybrid joint structural components;
2) for the aeronautical repair centres: a useful procedure for structural design and analysis with significant cost savings.

Key words*: aircraft, hybrid joint, adhesive bonding, strap joint (single and double), FEA, ANSYS*

1. INTRODUCTION

Although they seem, at first sight very simple components, riveted joints actually have a great importance both in terms of flight safety and economic point of view. As for a modern transport aircraft, millions of rivets are utilized, they should receive a special attention with a view to their share in the total cost and, especially, in flight safety. Aloha flight is already a classic case which, because of the fatigue fracture of large areas of the fuselage (see Figure 1) has created a particularly situation with respect to the flight safety [7].

Figure 1 Fatigue Fracture of Boeing 737-200 Fuselage Riveted Joints (combined with the effect of corrosion).

On April 28, 1988 a Boeing 737-200, flying the Hilo-Honolulu route (at an altitude of 7279 m) was severely damaged by fatigue fracture of a large section of the front fuselage.

The plane was 19 years of service during which a multi-site damage occurred. The case represents a spectacular example of degradation by corrosion resulting in damage by fatigue during normal operation of the aircraft.

An explosive decompression occurred and a piece of about 5.5 m of the cabin wall and structure behind the access door and above the passengers' room separated from the aircraft. There were 89 passengers on board and 6 crew members.

Seven passengers were seriously injured and a crew member was aspirated from on board.

Then, there was an emergency landing on the island of Maui. A solution with visible effects on fatigue resistance and improvement of joining technology is the use of hybrid joints (bonding + riveting).

The hybrid joint combines two methods, bonding and riveting, in order to provide more convenient properties than those obtained if each applies separately.

Usually, after bonding and hardening of the adhesive, the bonded parts are drilled, after which the rivets are mounted.

Compared to simple bonding, the hybrid assembling is more resistant to skinning (peeling), to static loading and impact stress, being also safer in operation and more resistant to variable stress.

In relation to the simple riveting, the hybrid assembly offers the advantage of greater rigidity due to the continuity of the joint.

2. ISSUE STATEMENT

Hybrid assembly (Figure 2) combines two methods, bonding and riveting, in order to provide more convenient properties than those obtained if each applies separately.

A simple technology includes: surface preparation, application of the adhesive, metal plates drilling, installing of rivets (after the adhesive hardening).

An important disadvantage is that fitting the rivets can dangerously damage the hardened adhesive.

More secure is fitting the rivets immediately after applying the adhesive (still unhardened).

Thus, hardening will occur with the parts assembled, maintained by the rivets in the correct relative position.

That technique is easy to apply because there are adhesives with a sufficiently long (from 1:00 to 12:00). "Open time" (The time from applying the adhesive to the initial substrate to when it hardens effectively).

For example, for epoxy adhesives, after fitting the rivets, curing may accelerate under the effect of temperature (by putting the assembled parts in the oven) [1].

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It is required to calculate the static behavior of a hybrid joint having junction plates either on one side or both sides (as in Figure 2).

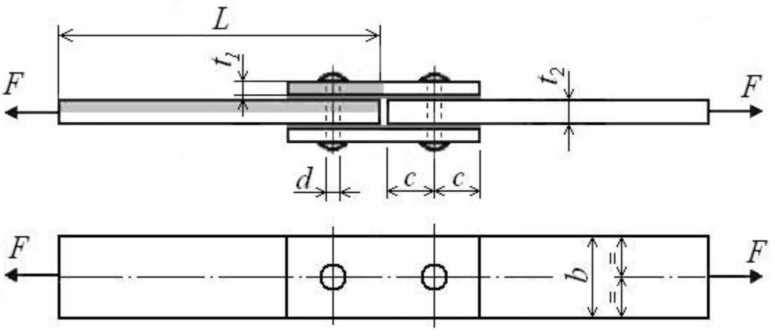

Figure 2 Hybrid assembly with junction plates on both sides

Using a 2-D parametric model it is possible to achieve a sensitivity study [1] in order to highlight the influence of the following parameters on the stresses values of the adhesive layer: a) thickness of the adhesive, b) overlap length c) rigidity of the adhesive d) thickness of the adherents.

3. INPUT DATA

In the study were considered:

- Two types of adhesive:

1. Mono-component epoxy adhesive, AV 119 (ARALDITE 2007), with the tensile strength σ_u = 70 MPa and the shear strength τ_u = 47 MPa;

2. Two -component epoxy adhesive, Bison-metal, with the tensile strength σ_u = 17 MPa and the shear strength τ_u = 12 MPa;

- Adhesives from aluminum alloy with the longitudinal elasticity modulus E_{Al} =70 000 MPa and the Poisson constant ν_{Al} = 0.33;

- Rivets from aluminum alloy with the longitudinal elasticity modulus E_{nit} = 68 500 MPa, transverse contraction coefficient ν_{nit} = 0.30, MPa, the shear strength τ_u=125 MPa and the shear yield strength $\tau_{0.2}$ = 60 MPa.

- Figures 3 and 4 show the characteristic curves for the aluminum alloy 2024-T3 and for the Bison - metal adhesive [1].

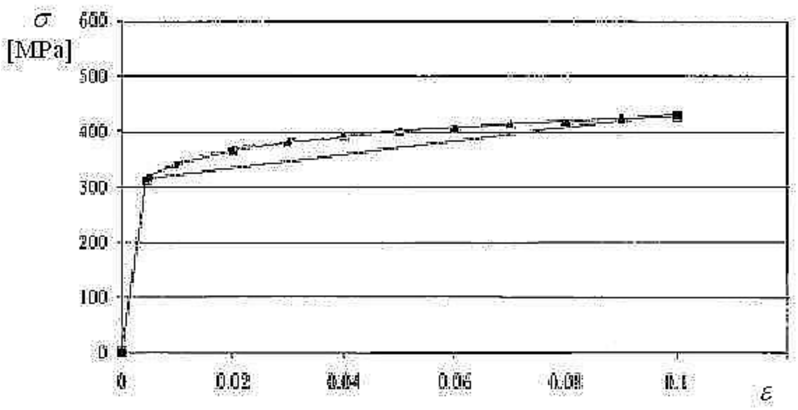

Figure 3 The characteristic curve for the aluminum alloy for the adhesive Bison-metal

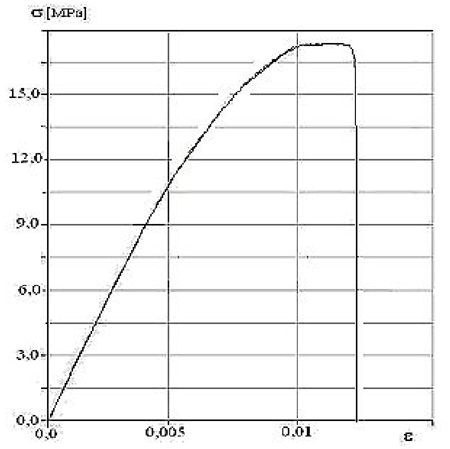

Figure 4 The tensile characteristic curve 2024-T3

Figure 2 shows the geometry of a join with junction plates on both sides, having the following dimensions: $L = 112.5$ mm, b=25 mm, $t_1 = t_2 = t = 1.6$ mm, length of adhesive layer $l_a = 2c = 12.5$ mm and thickness $t_a = 0.25$ mm.

The elastic parameters of the adhesive are: $E_a = 1250$ MPa, $\nu_a = 0.38$.

4. STATIC CALCULATION

The static calculation can be done either using traditional engineering methods [2], [8], [9], [10] or using the finite element technology [ANSYS [3]) which offers wider and more precise ways to study this type of structure.

The computing program utilized was ANSYS which has a rich library of finite elements that can model all types of joints that can be encountered in practice. First, a 2D calculation was performed to calculate the joint with adhesives. PLANE 82 element was used to model solid structures (PLANE 82 is best than PLANE 42 which also can be used).

For the calculation of riveted joints as well as of the hybrid joints a 3D analysis will be performed and SOLID 92, TARGE170 and CONTA174 elements will be used. The element is defined by eight nodes having two degrees of freedom at each node: translations in nodal x and y directions (the element has the same capabilities as PLANE 42). For the 3D analysis SOLID 45 can be also used. SOLID 45 is defined by eight nodes (see Figure 6) having each three degrees of freedom at each node: translations in nodal directions: x, y and z.

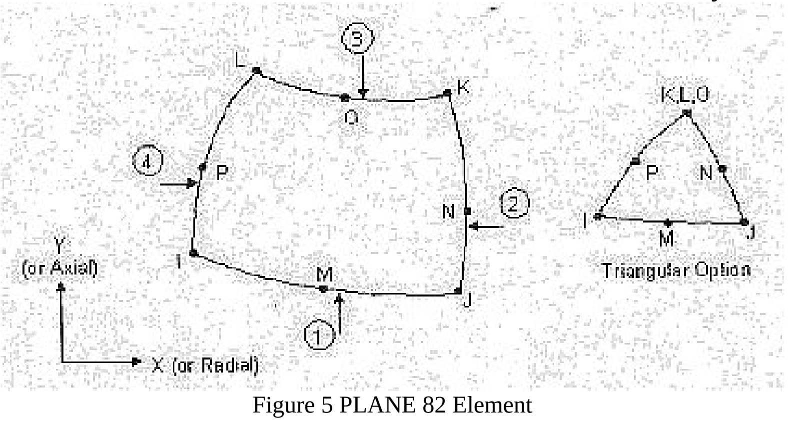

Figure 5 PLANE 82 Element

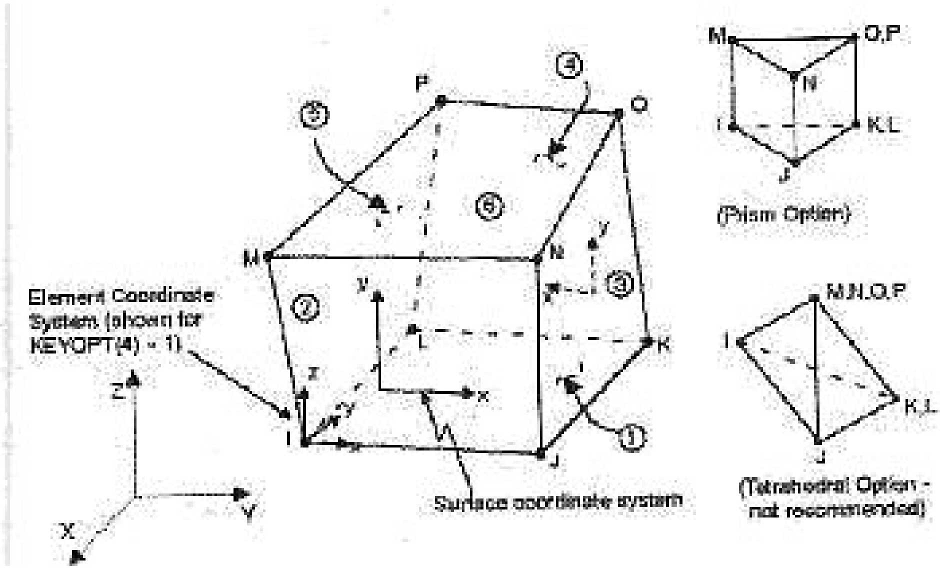

Figure 6 Solid 45 Element

SOLID 92 has a quadratic behavior and is very suitable for irregular networks .it also can tolerate irregular shapes without much loss of accuracy. The element is defined by 10 nodes (see Figure 7) each with three degrees of freedom per node: translations in nodal directions x, y and z.

The element has many capabilities such as plasticity, creep, swelling, stress stiffening, large displacements and large deformations. Also, the element is able to include orthotropic material characteristics.

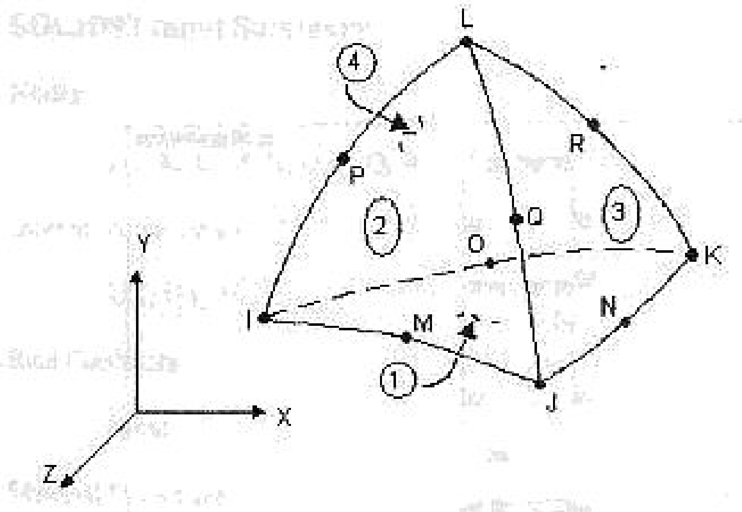

Figure 7 SOLID 92 Element

The unilateral junction plate model - figure 8 – with PLANE 82 has 32,475 nodes and 10,616 elements while the bilateral junction plate model has 57,572 nodes and 18,915 elements.

Due to its symmetry only half of the structure will be considered for the joint with a unilateral junction plate.

Due to the symmetry against both axes of coordinates only a quarter of the structure can be used for the bilateral junction plate model.

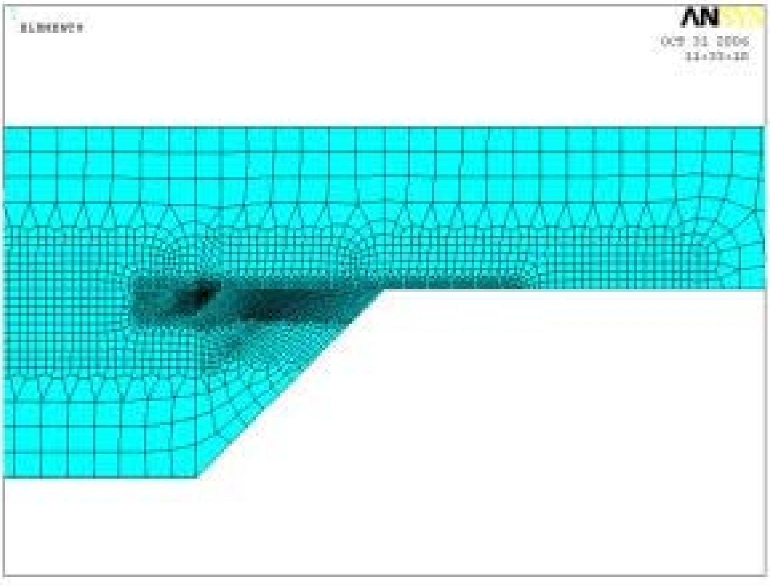

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Figure 8 2D Modelling with PLANE 82

For the bonded joints (without rivet) a 2-D model was issued with a finer mesh of the adhesive layer, adhesive-adherent interfaces and areas of stress concentration. Upper strip was guided horizontally (along the x axis) and subjected to force $F = b\ t_1\, \sigma_o$, which induces a tensile stress $\sigma_o = 10$ MPa.

TARGE170 element (Figure 9) is used to represent various 3D "target" surfaces for the associated contact elements (CONTA174).

Target surface is discretized by a set of target segments (see Figure 9) are paired with associated contact surface via real constants set. Any translational or rotational displacement on the target segment element can be imposed. Forces and moments on target elements can also be imposed. For rigid target surface, these elements can be easily modeled in complex target forms (e.g. rivets).

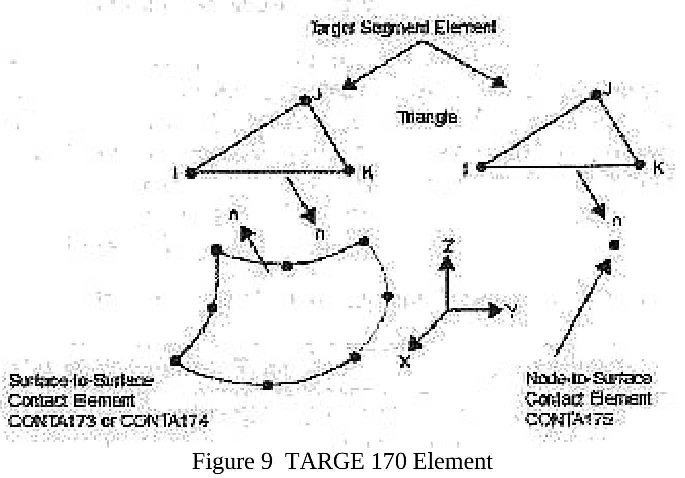

Figure 9 TARGE 170 Element

CONTA 174 (Figure 10) is used to represent the contact and sliding between 3D target surfaces and a deformable surface of this element.

The contact elements overlap the solid elements describing the boundary of the deformable body and are potentially in contact with the target surface (target) defined by TARGE170. The element is applicable to 3D structures and contact analysis at coupled fields. The element can be positioned on 3D solid surfaces or coated-type surfaces with knots in the middle of the sides (e.g. SOLID 92). The element has the same geometric features as the solid element to which it is connected.

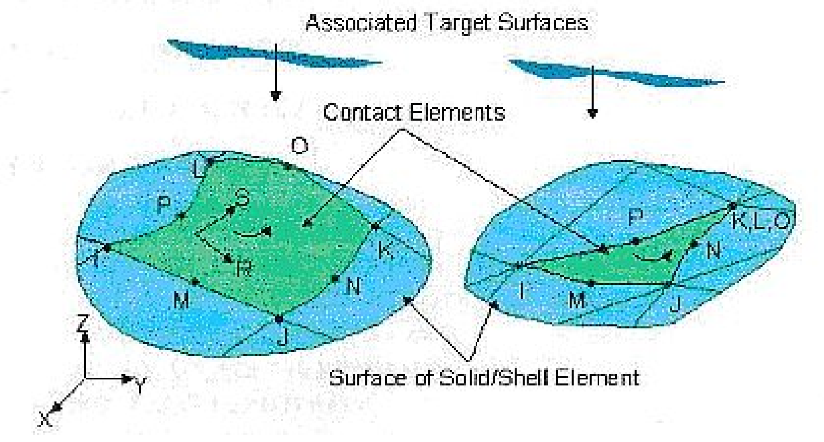

Figure 10 CONTA 174 Element

The geometry and element nodes locations are shown in Figure 10. The element is defined by eight nodes (the solid over which it is placed has nodes in the middle of the sides). The order of nodes is consistent with solid nodes over which it is placed. 3D surface contact elements are associated with 3D target elements via the real constant set.

The finite element model is designed so that it leads to a better approximation of the distribution of stresses in joint elements. In areas with high stress gradient (the extremity of the overlap section) the finite element mesh is refined. In the middle area of the joint (i.e. over 70% of the section overlapping the plate sheet-junction- plate) the stress distribution is approximately uniform. Thus the critical joint regions are those at the ends of the adherent-adhesive interface. In addition, the adhesive thickness (where possible) is divided by a mesh of some elements in order to get the tensions variation on the adhesive thickness.

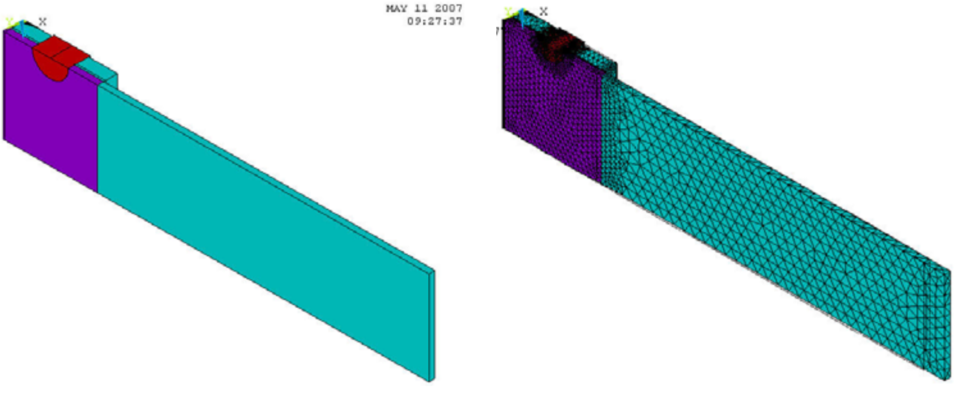

Figure 11 The 3 D model of junction

Figure 12 shows the plane model of a bonded joint, with a single junction plate (due to the symmetry only half of the structure has been modeled) and Figure 13 gives the spatial model of the hybrid junction plate joint (by bonding + riveting).

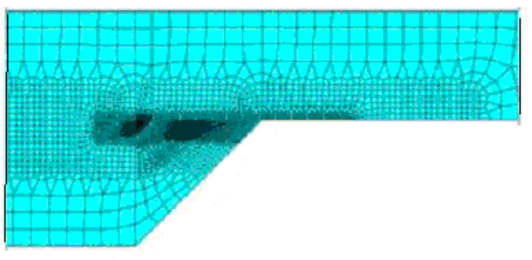

Figure 12 Plane model for a bonded joint with a single junction plate

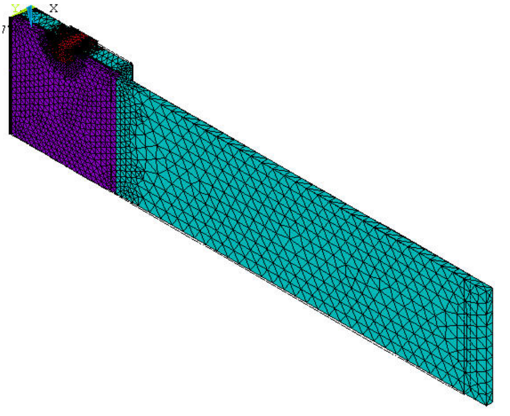

Figure 13 Spatial model of a hybrid joint with junction plate

The finite elements mesh was refined in areas with high stress gradient (ends of the overlap area).

Figure 14 presents the variation of stresses in the median plane of the adhesive. One can find that joint critical areas are the extremities of the adhesive –junction plate interface, an area where cracking will start, if the load reaches the limit value. The situation can be improved by using a junction -plate of variable thickness.

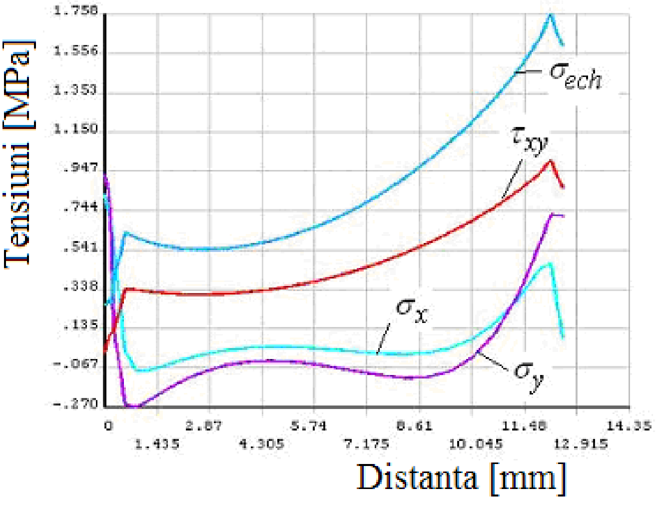

Figure 14 Stresses distribution in the median plane of the adhesive

5. CONCLUSIONS

Hybrid joints obtained by bonding and riveting, correctly made, have superior performance to those bonded. If bonding is performed first and rivets are mounted after the adhesive hardening, less resistant assemblies are obtained if compared with the case of rivets fixed before curing when more resistant junctions can be obtained.

In this case the adhesive penetrates into the space between the rivet body and plate sheets and it hardens while the assembled parts are maintained by the rivets in the correct relative position [1].

The experimental result given in paper [1] on hybrid joints is very interesting. Figure 15 shows firstly the response of the joint when the rivet and adhesive are operating; then, when the adhesive broke, a sudden force decrease can be observed (supported only by rivets).

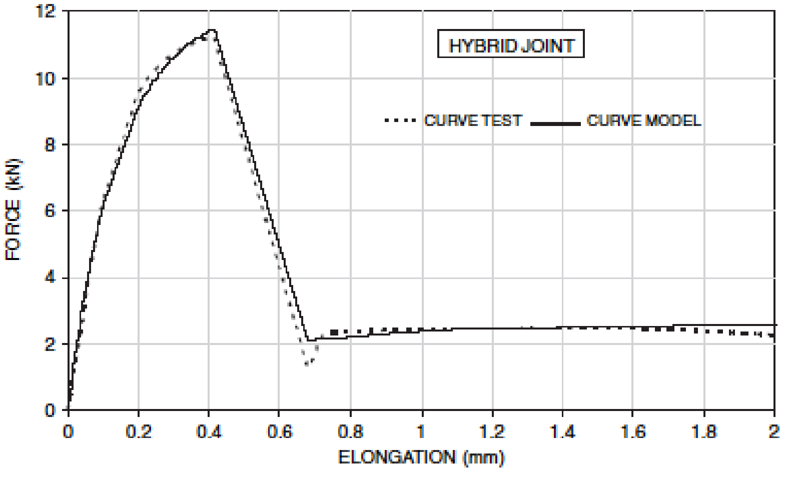

Figure 15 Behavior of a hybrid joint

In the design of the bonded and hybrid joints the main role is played by:

- the material and thickness of adherents;
- the thickness of the adhesive layer;
- the adhesive flexibility.

In case of joins with single or double junction plates, the best solution for reducing the stress peak at the ends of the overlap area is the use of junction- plates of a variable thickness. Also, the excess of the adhesive expelled under adherents can be modeled before hardening as a filler junction.

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