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Comparative study of the resistance of bonded, riveted and hybrid assemblies; Experimental and numerical analyses

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Abstract. The objective of this work is to analyze by traction tests, the mechanical behavior of an assembly of type metal / metal by various assembly processes; bonding, riveting and hybrid, on the one hand to show the advantage of a hybrid assembly with respect to the other processes, and on the other hand, to analyze by the finite element method the distribution of the stresses in the various components of the structure and to demonstrate the effectiveness of the use of a hybrid assembly with respect to other processes. The number of rivets has been considered. The results show clearly that the value of the different stresses is reduced in the case of a hybrid junction and that the number of rivets in an assembly can be reduced by using a hybrid joint.

Keywords: riveted-bonded joint; Von Mises stress; Absorption Energy; steel E24

1. Introduction

The manufacturing of a structure generally requires the assembly of the different parts. Various methods are used to assemble these parts, namely riveting, welding and bonding. Bonding is a technique more and more used in many industrial fields as in aerospace, automobile or even medicine. The adhesive bonds offer many advantages, particularly the assembly of materials with different nature or of composite materials (Adams 2005), (Da Silva and Ochsner 2008), (Karachalios *et al*. 2013), (Mokhtari *et al*. 2013), and the uniform load distribution over the entire bonded surface. However, major disadvantages of this assembly technique are a limited heat resistance, a sensitivity to moisture and aging (Rezgani *et al*. 2017). The resistance of a joint is directly related to the behavior of the adhesive which usually shows lower properties than those of the substrates. The analysis of the adhesive behavior was the primary concern of researchers. From the first works (Völkersen 1938), many models were developed on single or double lap joint (Goland 1944), (Tong 1994), (Osnes and McGeorge 2009), (Zhang *et al*. 2013).

To take full advantage of the benefits of bonding over mechanical fastening, considerable research has been done over the past several decades in bonding of aluminum. Significant works have been done in the areas of anodizing, etching, and other surface preparation methods for metals. A detailed study of adhesive bonded metallic structures is reported in the Primary Adhesively Bonded Structure Technology (PABST) Program (Thrall 1977 Thrall 1979). Earlier studies on adhesive-bonded joints can be found from the review papers by Matthews *et al*. (1982) and Vinson (1989). They proposed a shear lag model and considered only shear deformation of the adhesive. Hart-Smith (1973) and Lees (1985) included the elasto-plastic behavior of the adhesive. All these theoretical studies neglected shear deformations of the adherent and did not provide detailed stress concentrations at critical regions. However, improved theories, including nonlinear geometric and material effects of the adhesive and adherents have been presented (Tsai and Morton 1994), (Harris and Adams 1984). The finite element method is widely used in technology and its application to the determination of stresses in structures assembled by adhesive has a great advantage. Wooley and Carver (1971) made one of the first finite element analysis of a single lap joint. They used elements in the state of plane stress and the results were comparable to those of Goland and Reissner (1944). Cooper and Sawyer (1979) performed a two-dimensional finite element study of a single lap joint by using non-linear plane stress element analysis. Several studies have been devoted to the study of bonding processes performance by experimental and numerical methods thanks to the analysis of the stress distribution in each assembly substrate and provided later solutions to reduce these constraints by changing the geometry of the substrate and the adhesive (Elhannani *et al*. 2016), (Zhang *et al*. 2013).

Riveted lap joints are made up of aluminum alloys, composites and metal /composite combination. They are the structural components commonly used for the assembly of

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parts in civil aircraft structures. There is an assumption in conventional design processes: the rivet loads are shared equally among the rivets in the joint. Over the last decade, intensive research has been conducted to understand the process and performance of such assemblies. The joining ability of various grades of aluminum, high strength steel and even sandwich materials were evaluated (White 2006), (Leitermann and Christlein 2000), (Abe *et al*. 2009), (Lopez- Arancibia *et al*. 2015). This technique provides an assembly of good electrical conductivity and ease of disassembly of the components (Levente and Laszlo 2015). The major problem that arises in a riveted joint is the high stress concentrations around the fixing holes which increases the risk of failure of the structure. Several research studies have been done to study the mechanical behavior of the riveted structures by analytical approaches, experimental and numerical simulations (Reid and Hiser 2005), (Chakhari *et al*. 2008),(D'Aniello 2011), (Langrand and Eric Markiewicz, 2009), (Ertekin Öztekin 2015) and under several solicitations (Guo *et al*. 2016).

Therefore, the combination of adhesive bonding with other joining techniques could be an ideal solution for designers. Indeed, the use of adhesives presents benefits in term of strength and potential weight reduction. However, designer must take into account the problem of separation and aging of the adhesive. This appropriately chosen joining technology can offer significant enhancements of structural system performances in terms of effectiveness, reliability, safety and other design criteria. The modern applications of hybrid joints (e.g. bonded/riveted, (Gomez *et al*. 2007), (Pirondi and Moroni 2003), (Solmaz and Topkaya 2013) with adhesively bonded columns, bonded/bolted (Kelly 2006), (Paroissien *et al*. 2007)) are of great technological interest as they permit to combine and to enhance the individual performance of each kind of joint.

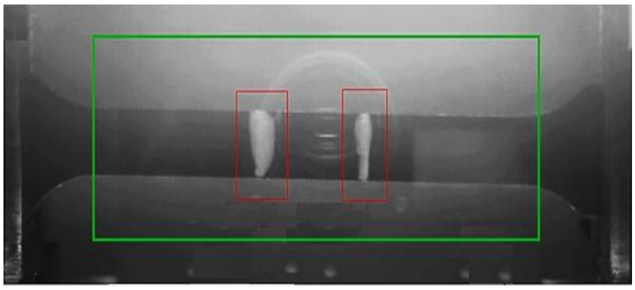
However, few studies have focused on the study of this type of process. Our goal is to study by tensile testing, the mechanical behavior of a single lap joint type steel / steel made by different joining configurations (bonding, riveting or hybrid assembly). First, we propose to show that the use of a hybrid assembly improves the bonding strength and can minimize the number of rivets in the structure.

Secondly, through the numerical modeling by finite elements, we propose to determine the distribution of the different stresses in the different substrates of the assembly and to see the reduction of this stresses concentration in the adhesive and rivets according to the different assembly methods.

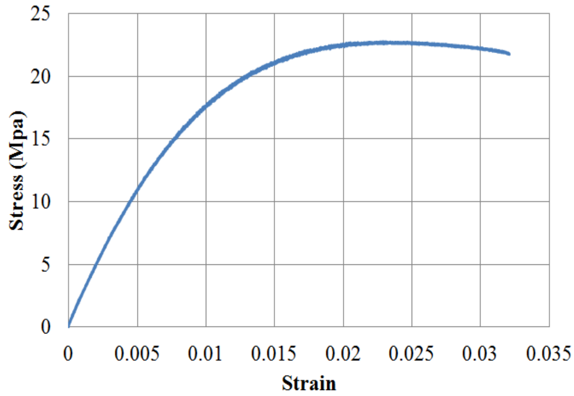
2. Experimental procedure

2.1 Mechanical properties

For the realization of bonded joints, the two steel plates are assembled by a bi-component epoxy adhesive, manufactured by AXSON and named "ADEKIT A140". This adhesive is widely used in various fields (aeronautics, marine, automotive…) for its high mechanical characteristics. It has a high mechanical and thermal resistance up to 100 °C.



(a) Tested specimen



(b) stress-strain tensile curves for ADEKIT A140 adhesive

Fig. 1 Characterisation of the ADEKIT A140 adhesive

Table 1 Mechanical properties of the ADEKIT A140 adhesive

Properties	Values
Young's modulus [MPa]	2660
Tensile strength [MPa]	22.7
Yield strength [MPa]	7.02
Poisson's ratio	0.35

Table 2 Mechanical properties of the E24 steel

Properties	Values
Young's modulus [GPa]	205
Tensile strength [MPa]	340
Yield strength [MPa]	235
Shear modulus [Gpa]	80
Poisson's ratio	0.3

The adhesive curing takes place at room temperature and can reach 3 days in order to obtain its final properties (see Fig. 1). The adhesive specimens are manufactured in a mold made of aluminum and PMMA (see Fig. 1.a).

The tensile tests were carried out with a ZWICK machine equipped with a 30kN force sensor with a loading speed of 0.5mm / min.

The mechanical properties of two E24 steel plates are shown in Table 2.

2.2. Geometry of specimens

To study the mechanical behavior of single lap joint under tensile test, we consider two E24 steel plates

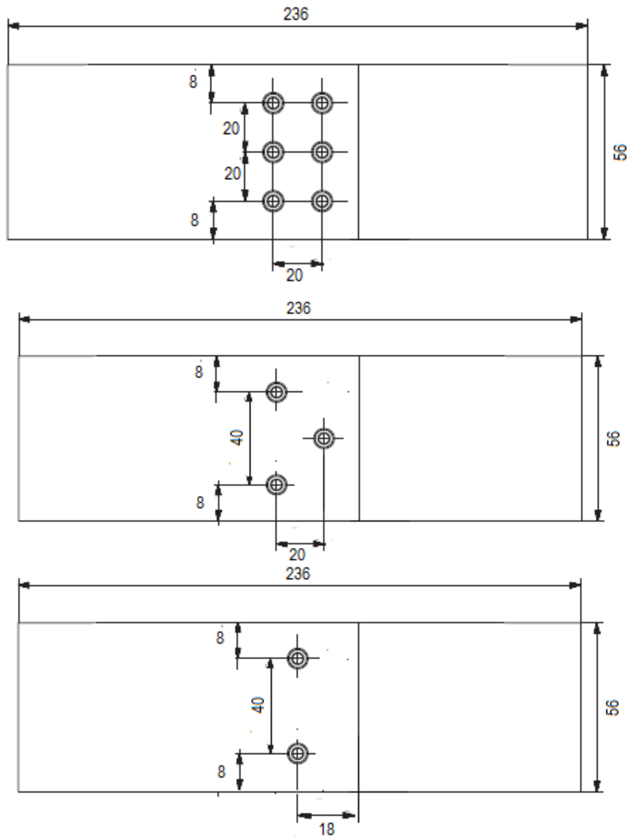


Fig. 2 Presentation of the riveted joint with different dimensions (mm); case of 2, 3 and 6 rivets

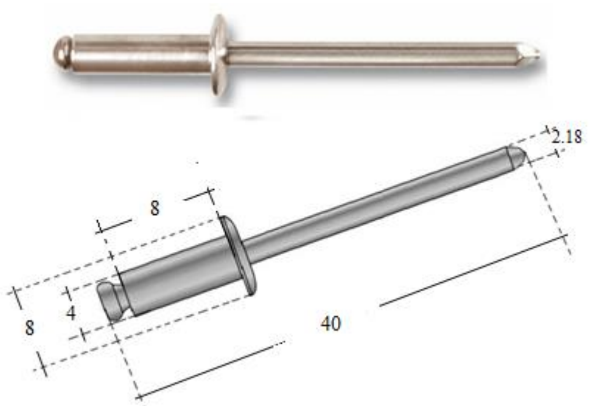


Fig. 3 Dimensions (mm) of the rivet

connected by different methods (bonding, riveting and hybrid). The transfers of charge into the substrate and the variation of the rivet number when adding the adhesive (hybrid assembly) were taken into consideration.

In riveted assemblies, the number of rivets was taken into account (2, 3 and 6 rivets). The rivets are made of aluminum alloy with a diameter d=4 mm (see Figure 3). The riveting of the two plates is carried out using a hand riveter (cold riveting) and the distance from the rivets to the edge of the plate is normalized and is between 1.5d and 2.5d, where d (mm) is the diameter of the rivet. The distance between the rivets is fixed at 5d (see Figure 2) along the lap length.

For the bonded joint, the surfaces to be bonded were treated by fine sanding, passed to the polisher for brazing and then rinsing with distilled water. The last step is to clean with acetone to remove the oxide layer. The bonding area is 36x56mm with an adhesive thickness (e_a) of 0.2mm (see Fig. 4).

The last joint to be tested is the hybrid joint which combines the two types of assembly tested above (riveted and bonded). For this joint, we keep the same dimensions of the plate and the rivet position (see Figure 5). The same conditions of experimental test were used. Figure 6 shows the joints during the experimental tests.

At least three samples of each assembly have been tested. Sometimes, specimens have slipped into the chuck jaws of the machine, so another samples have been added (see Table 3).

3. Experimental results

The various traction tests are presented in the form of force-displacement curves for the different configurations in order to analyze the results. The results of the samples assembled only by rivets, are grouped and shown in Fig.8, and those containing adhesive are shown in Fig. 9.

For the different configurations, the mechanical behavior is almost similar. At the beginning of loading, a significant displacement is observed for a low charge. On the other hand, if a certain load is exceeded, the value of which differs from one configuration to another, the slope of the curve increases considerably.

By increasing the number of rivets, the structure is more resistant to the applied load since the curve slope is increasingly acute.

The applied force is transmitted directly to the rivet, causing the plasticization of the latter before it is completely sheared. The presence of crumpling of the plate is totally negligible, since the plate is too hard with respect to the rivet (Figure 8).

Table 3 Presentation of the different joint samples for the tensile test

Type	Description	Number of samples
Configuration1	Riveted joint with only 2 rivets perpendicular to the axis of loading	5
Configuration2	Riveted joint with only 3 rivets in the shape of a triangle	3
Configuration3	Riveted joint with 6 rivets divided into two rows	3
Configuration4	Single lap joint with ADEKIT A140 adhesive	5
Configuration5	Hybrid joint contains 1 rivet with the adhesive layer 'ADEKIT A140'. The rivet has been installed before the curing of the adhesive	5
Configuration6	Hybrid joint with 2 rivets perpendicular to the loading axis and containing the adhesive layer 'ADEKIT A140'	3
Configuration7	Hybrid joint with 3 rivets containing the adhesive layer 'ADEKIT A140'.	3

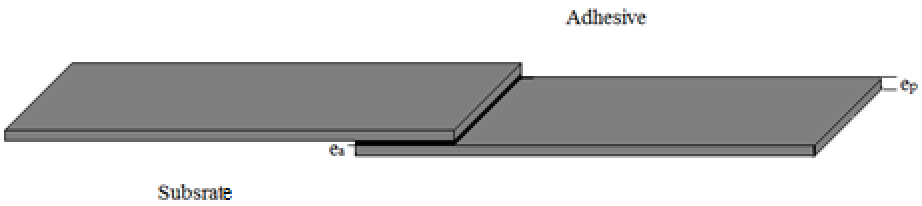


Fig. 4 Geometry of the bonded joint

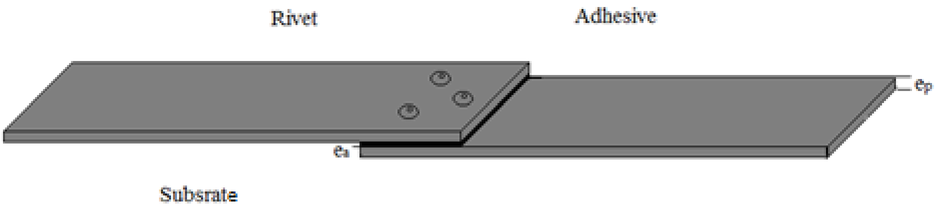
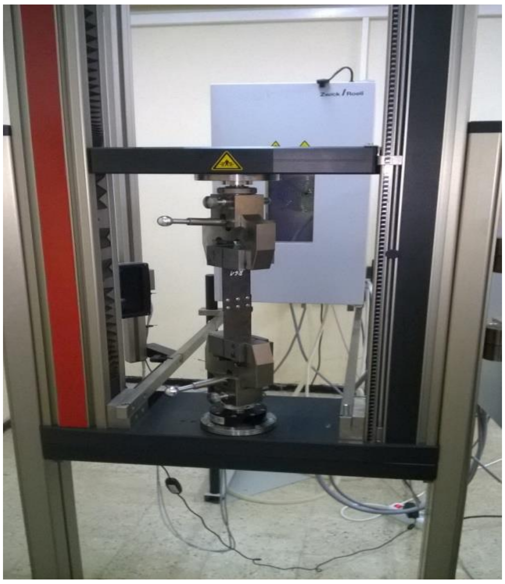


Fig. 5 Presentation of the hybrid joint



(a) Tensile tests of the riveted joint (6 rivets)

(b) Tensile tests of the hybrid joint (3 rivets)

Fig. 6 Tensile tests of riveted / hybrid joints

Fig. 7 Presentation of the different configurations after tensile test

The Figure 7 shows the photos of different configurations after the tensile test.

In Fig. 9, the hybrid assembly presents the same behavior than the bonded assembly. However, the values of the applied force and displacement are significantly higher in the case of the hybrid assembly. The slope change of the curve is different from one configuration to another. The joint with only the adhesive has a low force value and is therefore less resistant than hybrid joints.

The applied force is transmitted to rivet and adhesive together and a small portion to the plate.

The mechanical behavior of hybrid joints is much better. The increase in the number of rivets reinforces the mechanical strength of the joint and minimizes the stress concentration at the rivets and in the vicinity of the holes in the plates.

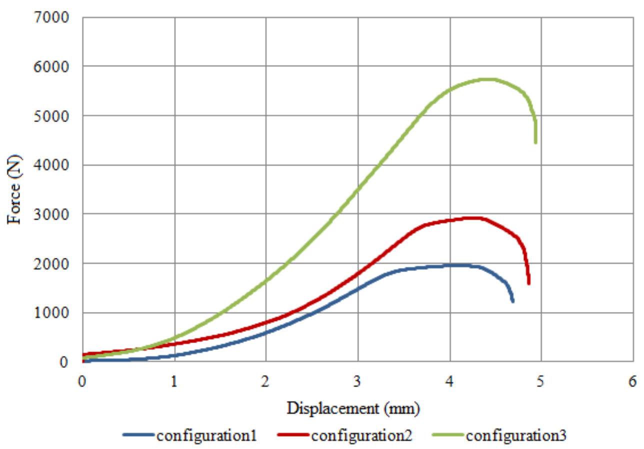


Fig. 8 Force-displacement curve for the riveted joints

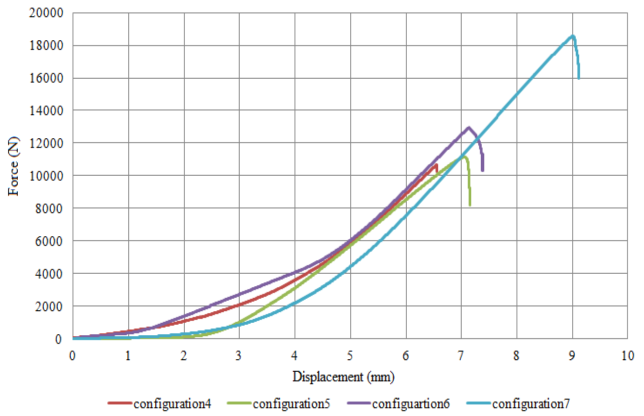


Fig. 9 Force-displacement curve for the bonded and hybrid joint

So, by the use of a hybrid joint, one can clearly reduce the number of rivets in a riveting assembly structure and prevent the stress concentration.

To highlight the behavior of different configurations, the maximum values of force and displacement for each type of assembly are plotted (respectively Fig. 10 and Fig. 11).

It is clearly noted that the maximum force in a riveted joint increases from 2000N in the case of two rivets to 6000N for the case of six rivets. Increasing the number of rivet causes the creation of stress concentration and also additional weight. The increase of rivet number in the overlap area can cause a deterioration of the plate, since the rivet hole may be located near the free edge of the plate. However, the presence of the adhesive increases the joint strength more than twice that of the 6-rivet joint and six times in the case of the 2-rivet joint.

The behavior is almost similar for hybrid assembly (with 1 rivet) and joint with only adhesive: they have almost the same maximum force value. The hybrid configuration (with 3 rivets) is clearly better than for the other configurations in terms of force and displacement. The force value is nine times higher than a 2-rivet assembly, three times higher than of a 6-rivet assembly and almost twice higher than a bonded assembly.

For the riveted configurations, the maximum displacement value is almost identical regardless of the rivet

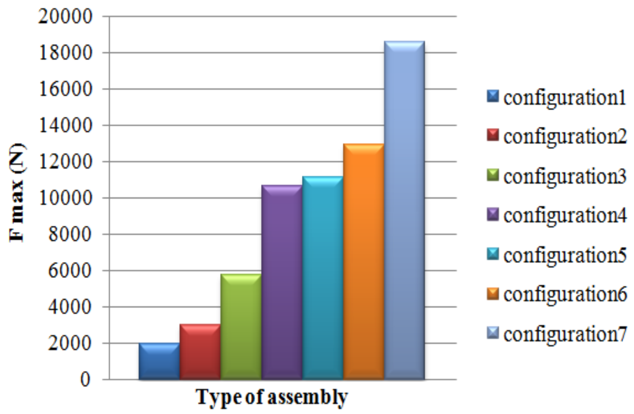


Fig. 10 The maximum force value for each type of assembly

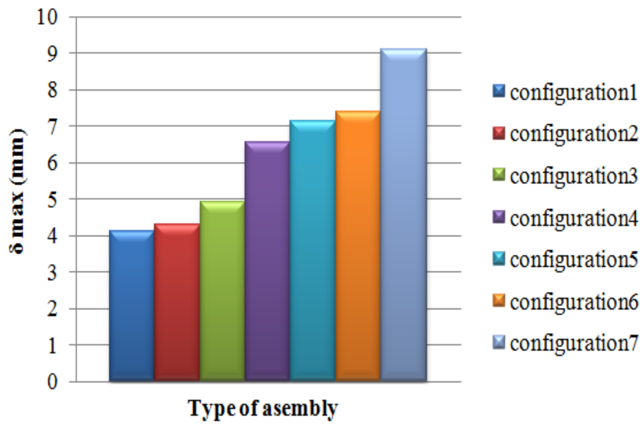


Fig. 11 The maximum displacement value of each type of assembly

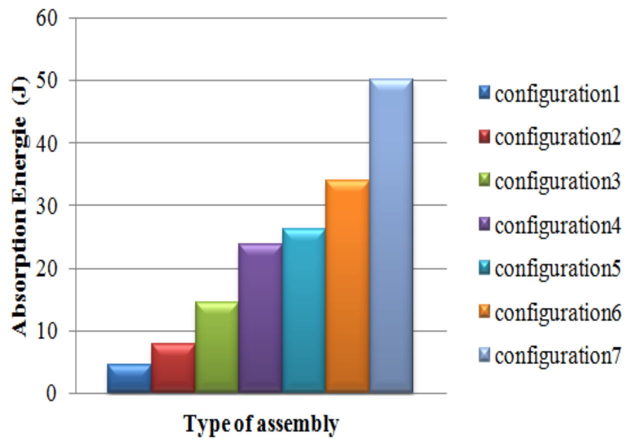


Fig. 12 Value of energy dissipation for each type of assembly

number. However, the hybrid configurations have significantly higher displacement values (almost twice) compared to bonded and riveted ones.

Regarding the joint weight, a simple 6-rivet joint has the same weight as a hybrid joint with 1 rivet. So the rivet number in a joint can be reduced by replacing rivets by an adhesive layer. Nevertheless, the performance for the hybrid joint is higher and allows to avoid the disadvantages of simply riveted and simply bonded joints.

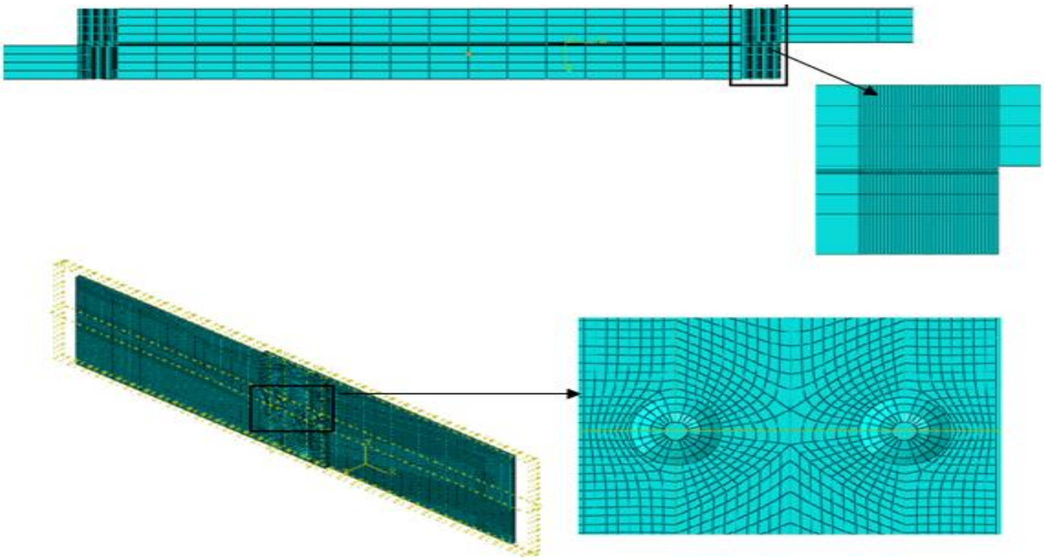


Fig. 13 Meshing of the bonded and riveted joint

4. The Energy variation

The absorption energies (Fig. 12) are calculated from the areas of the experimental curves of tensile tests for each configuration. Analysis of Fig.12 shows and confirms the results obtained in the Fig. 8 and Fig.9. The configuration 1 needs an energy of 4.5J to be fractured. The addition of rivets requires a higher energy to reach the failed point (configurations 2 and 3) which respectively equals to 7.77J and 14.57 J.

The increase in the rivet number has a proportional effect onto the energy value. An increase of almost 69% was noted for the case of the 3-rivet assembly compared to a 1- rivet one.

The obtained results show that the joints with a hybrid configuration are better than the riveted joints and bonded ones, where the dissipation energy for the single lap joint is equal to 23.84J whereas it is respectively equal to 26.28J, 34J and 50.21J for configurations 5, 6 and 7. Configuration 7 has the highest dissipation energy compared to other configurations, which proves that the hybrid joint with 3 rivets has a good failure strength with a 84% improvement over a 3-rivet joint, and 53% compared to a single lap adhesive joint.

5. Numerical study

A three dimensional (3-D) finite element model was created in order to investigate numerically the three types of plate assembly. The following types of elements were applied to the analysis: 8-node brick elements of type C3D8R with reduced integration for modelling the behavior of steel plates, 4 node tetrahedral elements were used for the rivet modelling and 8-node three-dimensional brick elements for the adhesive layer. The analyses were done with the implicit version of the ABAQUS finite element code. An interaction 'penalty' between the riveted plates and an interaction 'hard contact' between rivet and plates were used. The analysis included both material and geometrical non-linearities.

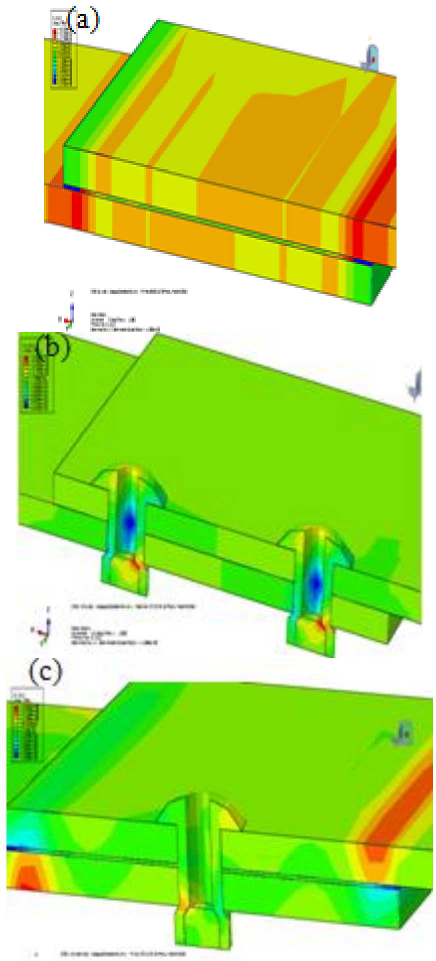


Fig. 14 Shear stress distribution in (a) bonded, (b) riveted, (c) hybrid joint

The mechanical properties of the plates, rivet and adhesive presented in Tables 1 and 2 were introduced into the ABAQUS numerical code.

The dimensions of the plates, rivets and adhesive are the same as those used in the experimental part, as well as the boundary conditions namely an applied load of 10Mpa.

The Fig. 13 shows the mesh of bonded and riveted joint.

Figure 14 shows the stress level in the different assemblies of the two steel plates, where it is seen that the stresses are not uniform in the different plates during loading. For adhesive bonding, the concentration of the stresses is at both edges of the adhesive while its core remains almost inactive. On the other hand, for the riveted assembly, stress concentration is located in the middle of the rivets and in the vicinity of the hole. For the case of a hybrid joint, the stresses decrease, one part locates at the edge of the adhesive and the other part at the level of the rivet and the plate.

5.2 Distributions of the maximum stresses in the adhesive layer and rivets

Numerical analysis of the behavior of the various assemblies allows us to analyze the distribution of the different stresses in the different elements of the structure (rivet and adhesive plate).

Fig. 15 presents the different maximal stresses in the adhesive and rivet for each configuration. The values of the different stresses decrease by increasing the rivet number in the structures, and decrease further by adding the adhesive. The stresses are maximum for riveted assembly with only one rivet.

For an applied load equal to 10Mpa, the Von Mises stress exceeds 300 MPa (almost breaking of the rivet) and decreases to almost 250 times for a hybrid joint with 3 rivets. Shear stresses are important in the joint with only rivets. The presence of the adhesive distributes all the stress in a larger area and reduces its value by almost 10 times in the case of a hybrid joint.

5.3 Distributions of the maximum stresses in the plates

To see the effect of the presence of the rivet and the adhesive on the stress distribution in the plate, Fig. 16 represents the variation of the Von Mises stress in the plates for each configuration of the assembly.

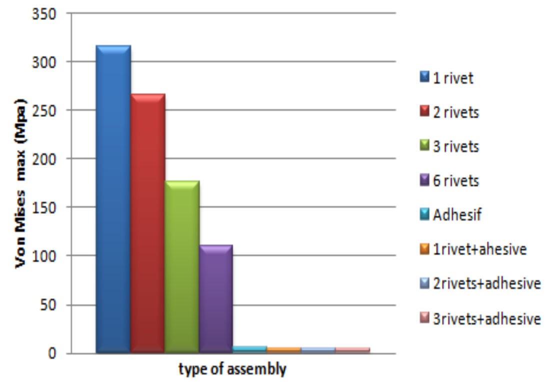
The joint with a single rivet has the highest stress value. One can clearly see that the value of the stress is important in the plates for the case of riveted joints and decreases when the rivet number increases.

For hybrid joints, the stresses are significantly lower in the plates and are reduced to approximately 85% compared to a joint with 1 rivet and 60% compared to a joint with 6 rivets.

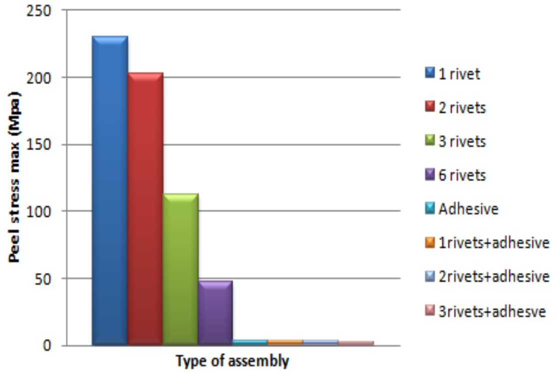
Generally, the stress value in the steel plates remains significantly lower in most of the joints and do not exceed the elastic limit of the material.

5.4. Stress distribution according to the half width and half length of the plates and adhesive

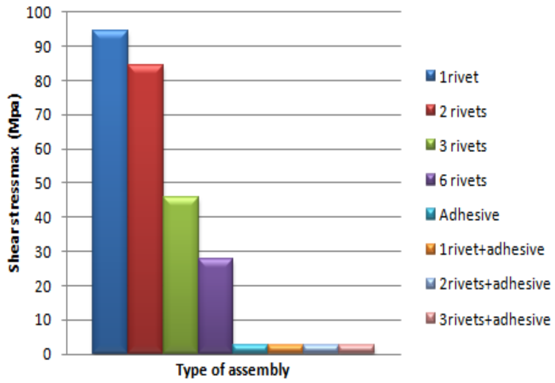
To investigate the influence of different configurations on the stress distribution in the overlap area, two lines following the mid width and mid length have been drawn (see Fig. 17).



(a) Von Mises stress



(b) Peel stress



(c) Shear stress

Fig. 15 Maximal stresses in the adhesive and rivet

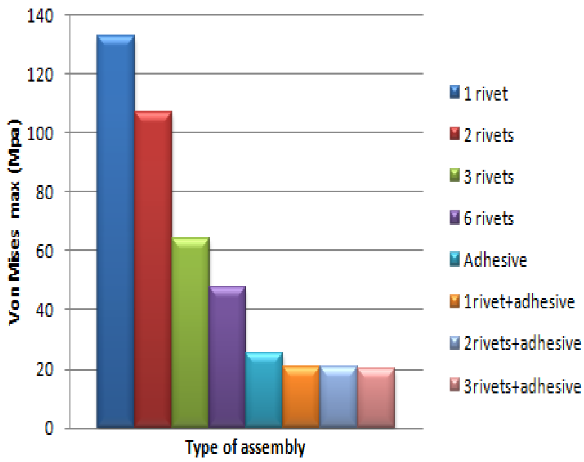


Fig. 16 The maximal Von Mises stresses in the plates for the different configurations

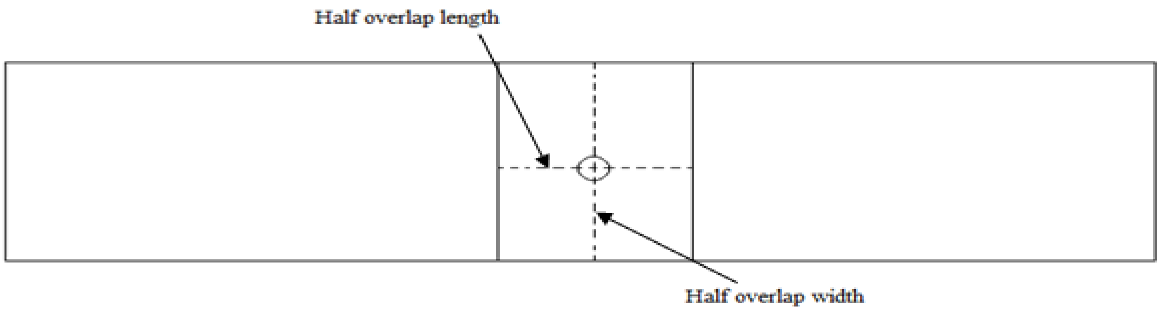
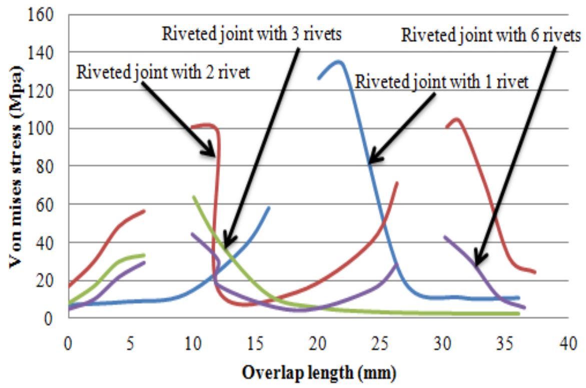
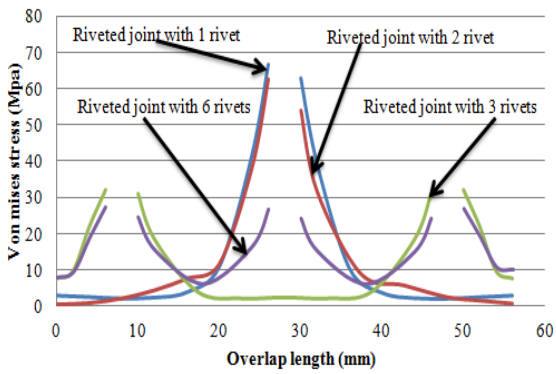


Fig. 17 Presentation of two lines along the width and half the mid length of the overlap region to determine the stress distribution

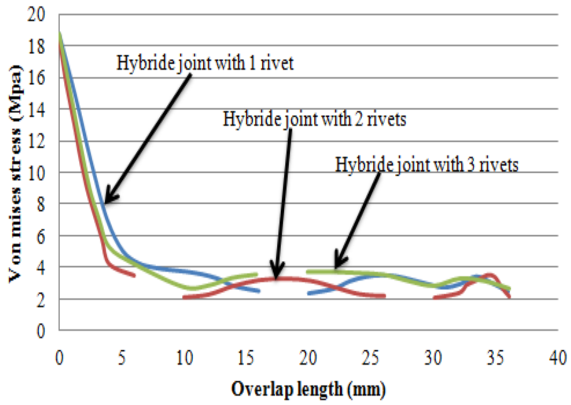


(a) Half overlap length

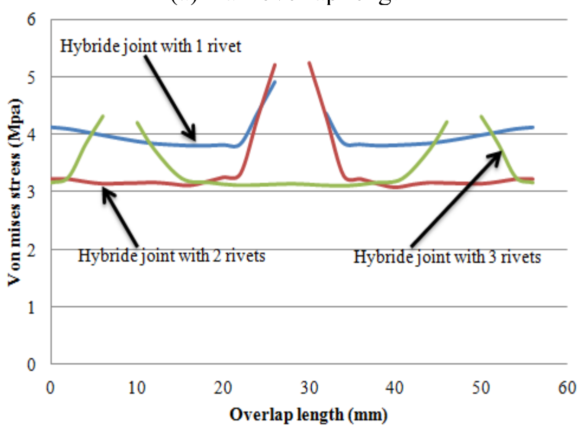


(b) Half overlap width

Fig. 18 Von Mises stress distribution on the plates for the riveted joint



(a) Half overlap length



(b) Half overlap width

Fig. 19 Von Mises stress on the plates for hybrid joint

The analysis of the Von Mises stress distribution in the plate following the half width and half length of the overlap area for the various configurations (riveted joints) is shown in Fig. 18. As can be seen, the stress distribution is not homogeneous, and there are stress peaks at the level of the rivet holes. The maximum stress value is for the riveted joint with one rivet and this value decreases gradually as the number of rivets increases.

In the vicinity of the holes, the stresses are higher along the loading axis (see Fig. 18.a) when compared with those being perpendicular to the traction axis (see Fig. 18.b).

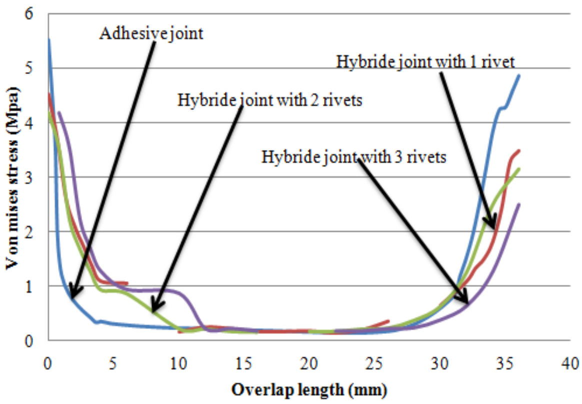
For the hybrid joints, the Von Mises stress values in the plates are small compared with those in the riveted joints (see Fig. 19). Von Mises stress values at the beginning of the plate are almost the same (18MPa) for different hybrid configurations, then these values decrease and stabilize going towards the end of the plate.

Similarly, the values of the Von Mises stresses are clearly superiors following the loading direction than that in the perpendicular direction.

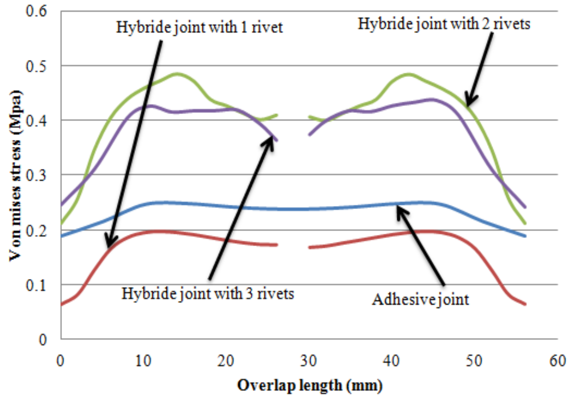
The Von Mises stress value is slightly higher in the case of two rivets as in the case of a single rivet because of the hole presence near the edge of the plate.

5.5. Stress distribution in the adhesive layer:

The Von Mises stress distribution in the adhesive layer is shown in Fig. 20. One notices that for this value of the applied load, the value of different stresses in the adhesive is low, and the adhesive absorbs some of this load. The rest

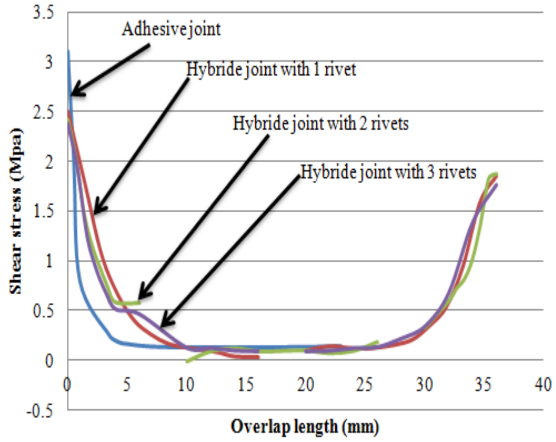


(a) Half overlap length

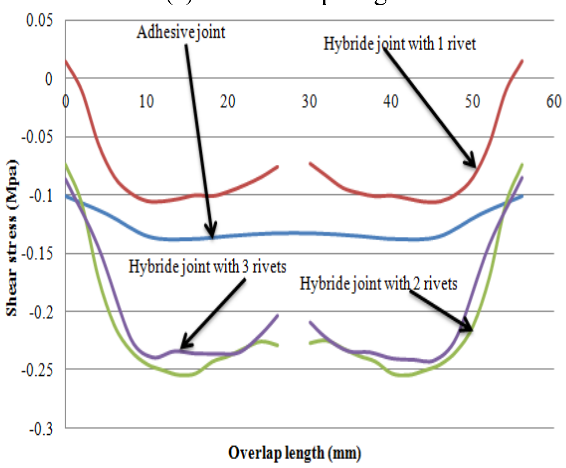


(b) Half overlap width

Fig. 20 Von Mises stress in the adhesive layer for bonded and hybrid joint



(a) Half overlap length



(b) Half overlap width

Fig. 21 Shear stress in the adhesive layer for bonded and hybrid joint

is distributed between the rivet and the plate. The stresses are highest at the adhesive edge and decrease going towards its heart. Despite the existence of stress concentrators in the adhesive (at the level of rivet hole), the stress values are significantly lower than those at the edge, since these rivet holes are located at the heart of the adhesive. Lower values are noted in the case of a hybrid joint with 3 rivets.

The same remark can be done for shear stresses (see fig. 21). The stresses are highest at the edge of the adhesive while the heart is almost inactive. The highest values of the stresses are noted in the case of the bonded joint. However, for the hybrid joint, the stresses are a little weak because the adhesive absorbs some of this stress and the rest is transmitted directly to rivet.

The presence of the rivet holes does not affect the shear stress value.

Following the mid-width of the adhesive, the shear stresses are significantly lower compared to those following the loading direction.

5.6 Stress concentration factor

Stress concentration factors were determined for riveted and hybrid assemblies (Fig. 22). It is clear that the stress concentration factor varies from one structure to another. The highest value is noted for the case of a riveted assembly with 1 rivet while the use of the hybrid joint reduces this value by more than 90%.

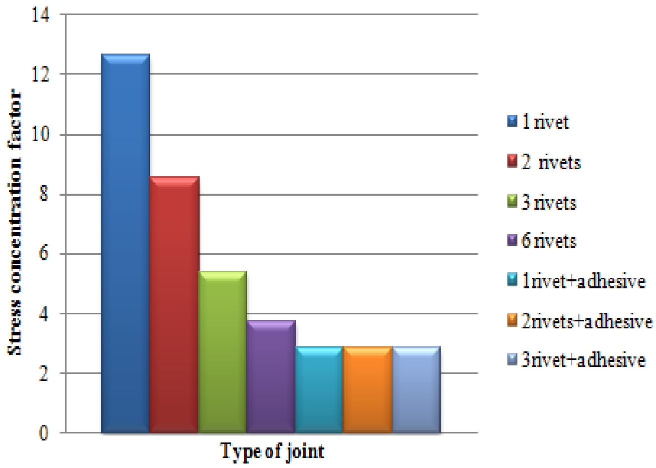


Fig. 22 Stress concentration factor in the plate for the different configurations

6. Conclusion

The study undertaken in this work aimed to characterize through tensile tests and numerical analysis, the performance of different E24 steel plate assembly methods namely riveting, bonding and hybrid.

The results of the traction curves clearly show that the strength of the hybrid joint is significantly higher than that of the riveted and bonded joints. The increase of rivet number in a riveted joint offers more resistance to the joint.

In a hybrid joint, the presence of the adhesive layer considerably reduces the rivet number by avoiding the presence of a stress concentration. The maximum force in a hybrid joint with a single rivet is equal to 3 times the value of that of the riveted joints with a single rivet.

In terms of weight, the hybrid joint (with 1 rivet) has the same weight as a riveted joint with six rivets.

In the hybrid joint, the stresses are transferred at the same time to the adhesive, the rivet and the plate, unlike the riveted joint where the stress concentration is located in the rivets.

References

Abe, Y., Kato, T. and Mori, K. (2009), "Self-piercing riveting of high tensile strength steel and aluminium alloy sheets using conventional rivet and die", *J. Mater. Process. Technol*., **209**(8), 3914-3922. https://doi.org/10.1016/j.jmatprotec.2008.09.007.

Adams, R.D. (2005), "Adhesive bonding: science", *Technol. Appl.*, Woodhead Publishing Ltd., Bristol, United Kingdom.

Chakhari, J., Daidie, A., Chaib, Z. and Guillot, J. (2008), "Numerical model for two-bolted joints subjected to compressive loading", *Finite Elem. Anal. Des*, **44**(4), 162-173. https://doi.org/10.1016/j.finel.2007.11.010.

Cooper, P.A. and Sawyer, J.W. (1979), "A critical examination of stresses in an elastic single lap joint", TP-1507; NASA.

D'Aniello, M., Portioli F., Fiorino, L. and Landolfo, R. (2011), "Experimental investigation on shear capacity of riveted connections in steel structures", *Eng. Struct.*, **33**(2), 516-531. https://doi.org/10.1016/j.engstruct.2010.11.010.

Da Silva, L.F.M. and Ochsner, A. (2008), *Modeling of Adhesive Bonded Joints*, Springer, Berlin, Germany.

Elhannani, M., Madani, K., Mokhtari, M., Touzain, S., Feaugas, X, and Cohendoz, S. (2016), "A new analytical approach for optimization design of adhesively bonded single-lap joint". *Struct. Eng. Mech.*, **59**(2), 313-326. http://doi.org/10.12989/sem.2016.59.2.313.

Goland, M. and Reissner, E.J. (1944), "The stress in cemented joints", *J. Appl. Mech. Tranc. Am. Soc. Mech. Eng*., **66**, A17-A27.

Goland, M., Buffalo, N.Y. and Reissner, E. (1944), "The stresses in cemented joints: Transaction of ASME", *Appl. Mech.*, **66**, A17-A27.

Gomez, S., Onoro, J. and Pecharroman, J. (2007), "A simple mechanical model of a structural hybrid adhesive/riveted single lap joint", *Adhes. Adhes*., **27**, 263-267.

Guo, X., Zewei, H., Xiong, Z., Yang, S. and Peng, L. (2016), "Numerical studies on behaviour of bolted ball-cylinder joint under axial force", *Steel Compos. Struct.,* **20**(6), https://doi.org/10.12989/scs.2016.20.6.1323.

Harris, J.A. and Adams, R.D. (1984), "Strength prediction of bonded single lap joints by nonlinear finite element methods", *Adhes. Adhes.*, **4**(2), 65. https://doi.org/10.1016/0143-7496(84)90103-9.

Hart-Smith, L.J. (1973), "Adhesive bonded double lap joints", NASA-CR-112237; McDonnell-Douglas Corp., Long Beach, CA, USA.

Karachalios, E.F., Adams, R.D. and da Silva, L.F.M. (2013), "Single lap joints loaded in tension with high strength steel adherends", *Adhes. Adhes.*, **43**, 81-95. https://doi.org/10.1016/j.ijadhadh.2013.01.016.

Kelly, G. (2006), "Quasi-static strength and fatigue life of hybrid (bonded/bolted) composite single-lap joints", *Compos. Struct.*, **72**(1), 119-129. https://doi.org/10.1016/j.compstruct.2004.11.002.

Leconte, N. and Langrand, B. (2009), "Hybrid displacement FE formulations including a hole", *Struct. Eng. Mech.,* **31**(4), 439-451.

Lees, W.A. (1985), "Stress distribution in bonded joints: An exploration within a mathematical model", *Mater. Des.*, **6**(3), 117-123. https://doi.org/10.1016/0261-3069(85)90054-8.

Leitermann, W. and Christlein, J. (2000), "The 2nd generation Audi space frame of the A2: A trendsetting all-aluminium car body concept in a compact class car", *Seoul 2000 FISITA World Automotive Congres*s, Seoul, Korea, June.

Levente, K. and Laszlo, D. (2015), "Experimental study on standard and innovative bolted end-plate beam-to-beam joints under bending", *Steel Compos. Struct.,* **18**(6), 1423-1450. http://doi.org/10.12989/scs.2015.18.6.1423.

Lopez-Arancibia, A., Altuna-Zugasti, A.M., Aldasoro, H.A. and Pradera-Mallabiabarrena, A. (2015), "Bolted joints for single-layer structures: Numerical analysis of the bending behavior", *Struct. Eng. Mech.*, **56**(3), 355-367. https://doi.org/10.12989/sem.2015.56.3.355.

Matthews, F.L., Kilty, P.F. and Goodwin, E.W. (1982), "A review of the strength of joints in fibre reinforced plastics: Part 2 Adhesively bonded joints", *Compos.*, **13**(1), 29-37. https://doi.org/10.1016/0010-4361(82)90168-9.

Mokhtari, M., Madani, K., Belhouari, M., Touzain, S., Feaugas, X. and Ratwani, M. (2013), "Effects of composite adherend properties on stresses in double lap bonded joints", *Mater. Design*, **44**, 633-639. https://doi.org/10.1016/j.matdes.2012.08.001.

Osnes, H. and McGeorge, D. (2009), "Experimental and analytical strength analysis of double lap joints for marine application", *Compos. B*, **40**, 29-40. https://doi.org/10.1016/j.compositesb.2008.07.002.

Öztekin, E. (2015), "Reliabilities of distances describing bolt placement for high strength steel connections", *Struct. Eng. Mech.,* **54**(1), https://doi.org/10.12989/sem.2015.54.1.149.

Paroissien, E., Sartor, M., Huet, J. and Lachaud, F. (2007), "Analytical two-dimensional model of a hybrid (bolted-bonded) single-lap joint", *J. Aircraft*, **44**, 573-582. https://doi.org/10.2514/1.24452.

Pirondi, A. and Moroni, F. (2009), "An investigation of fatigue failure prediction of adhesively bonded metal/metal joints", *J. Adhes. Sci.Technol*., **29**(8), 796-805. https://doi.org/10.1016/j.ijadhadh.2009.06.003.

Reid, J.D. and Hiser, N.R. (2005), "Detailed modeling of bolted joints with slippage", *Finite Elem. Anal. Des.*, **41**(6), 547-562.

Rezgani, L., Madani, K., Mokhtari, M., Feaugas, X., Cohendoz, S., Touzain, S. and Mallarino, S. (2017), "Hygrothermal ageing effect of ADEKIT A140 adhesive on the J-integral of a plate repaired by composite patch", *J. Adhes. Sci. Technol*., **32**, 1393-1409. https://doi.org/10.1080/01694243.2017.1415790.

Solmaz, M.Y. and Topkaya, T. (2013), "Progressive failure analysis in adhesively, riveted, and hybrid bonded double-lap joints", *J Adhes.*, **89**, 822-836. https://doi.org/10.1080/00218464.2013.765800.

Thrall, Jr. and Edward, W. (1977), "Primary adhesively bonded structure technology (PABST)", *J. Aircraft*, **14**(6), 588-594. https://doi.org/10.2514/3.58825.

Thrall, Jr. and Edward, W. (1979), "PABST program test results", *Adhes.*, **22**(10), 22-33.

Tong, L. (1994), "Bond shear strength for adhesive bonded double-lap joints", *Solids Structure,* **31**, 2919-2931.

https://doi.org/10.1016/0020-7683(94)90059-0.
Tsai, M.Y. and Morton, J. (1994), "An evaluation of analytical and numerical solutions to the single-lap joint", *Solids Struct.,* **31**, 2537.
Vinson, J.R. (1989), "Adhesive bonding of polymer composites". *Polym. Eng. Sci.*, **29**(19), 1325-1331. https://doi.org/10.1002/pen.760291904.
Volkersen, O. (1938), "Nietkraftverteilung in Zugbeanspruchten Nietverbindungen mit Konstanten Laschenquerschnitten", *Luftfahrtforschung*, **15**, 41-47.
White, M. (2006), "Aluminum & the automotive industry, Jaguar and Land Rover lightweight vehicle strategy", *21st International Aluminium Conference*, Moscow, September.
Wooley, G.R. and Carver, D.R. (1971), "Stress concentration factors for bonded lap joints", *J. Aircraft*, 817. https://doi.org/10.2514/3.44305.
Zhang, F., Wang, H.P., Hicks, C., Yang, X., Carlson, B., Zhou, Q. (2013), "Experimental study of initial strengths and hygrothermal degradation of adhesive joints between thin aluminum and steel substrates", *Adhes. Adhes*., **43**, 14-25.
Zhang, Fan., Wang, Hui-Ping, Hicks, C., Yang, Xin, Carlson, B.E and Zhou, Q. (2013), "Experimental study of initial strengths and hygrothermal degradation of adhesive joints between thin aluminum and steel substrates", *Adhes. Adhes.,* **43***,* 14-25. https://doi.org/10.1016/j.ijadhadh.2013.01.001.

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