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Review Article

Fatigue Behaviour of Fastening Joints of Sheet Materials and Finite Element Analysis

Xiaocong He,[1] Fengshou Gu,[2] and Andrew Ball[2]

[1] *Innovative Manufacturing Research Centre, Kunming University of Science and Technology, Kunming 650093, China*
[2] *Centre for Efficiency and Performance Engineering, University of Huddersfield, Queensgate, Huddersfield HD1 3DH, UK*

Correspondence should be addressed to Xiaocong He; hhxxcc@yahoo.co.uk

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Some fastening techniques such as self-piercing riveting, mechanical clinching, and structural adhesive bonding are efficient joining methods which are suitable for joining advanced lightweight sheet materials that are hard to weld. The recent literature relating to fatigue behavior of such fastening joints and finite element analysis is reviewed in this paper. The recent development in fatigue behavior analysis of the fastening joints is described with particular reference to some major factors that influence the fatigue behavior of the fastening joints: failure mechanism, environmental effects, and hybrid joining techniques. The main methods used in finite element analysis of fatigue behavior of the fastening joints of sheet materials are discussed and illustrated with brief case studies from the literature.

1. Introduction

Due to the need to design lightweigh thin-walled structures and the increased use of lightweight materials in different industries, some relative new joining techniques such as self-piercing riveting (SPR), mechanical clinching, and structural adhesive bonding have drawn more attention in recent years because they can join advanced sheet materials that are dissimilar, coated, and hard to weld [1–5].

Fatigue loading is a common cause of failure in the fastening joints. In order to understand the failure mechanisms and the influence of parameters, the fatigue behavior analysis of the fastening joints of sheet materials has been the subjects of a considerable amount of experimental and numerical studies [6–15]. The increasing complex joint geometry and its three-dimensional nature combine to increase the difficulty of obtaining an overall system of governing equations for predicting the fatigue properties of the fastening joints. To overcome these problems, the finite element analysis (FEA) is frequently used [16–24].

As self-pierce riveting and clinching are considered to be alternatives to spot-welding, most investigations have focused on comparisons of the mechanical behavior of joints manufactured by these techniques. Research in this area has shown that SPR and clinching gives joints of comparable static strength and superior fatigue behavior to spot welding, whilst also producing promising results in peel and shear testing. Figure 1 compares the fatigue behavior of SPR and clinching with spot welding [25]. Structural adhesively bonded joints are also the efficient method for joining both metallic and nonmetallic structures where strength, stiffness and fatigue life must be maximized at a minimum weight. Hybrid joints bring together the advantages of different fastening techniques. Published work relating to fatigue behavior analysis of the fastening joints of sheet materials is reviewed in this paper, in terms of fracture mechanics, effects of environmental conditions, and hybrid joining techniques.

2. Self-Piercing Riveting

SPR is a high-speed mechanical fastening technique used to fasten two or more sheets of material by driving a semitubular rivet through the top sheet(s), piercing the bottom sheet and spreading the rivet skirt under the guidance of a suitable die. As the process relies on a mechanical interlock rather

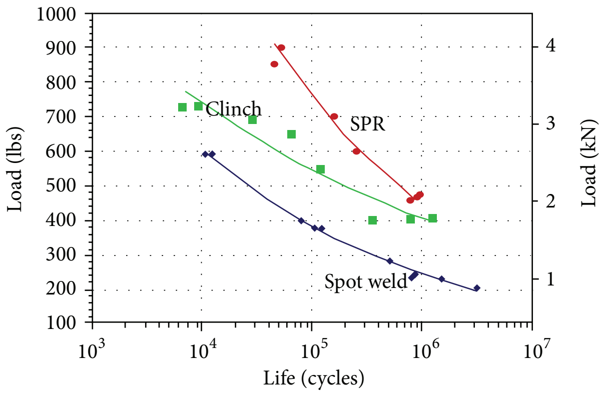


Figure 1: Fatigue behavior comparison of SPR, clinch, and spot-weld joints.

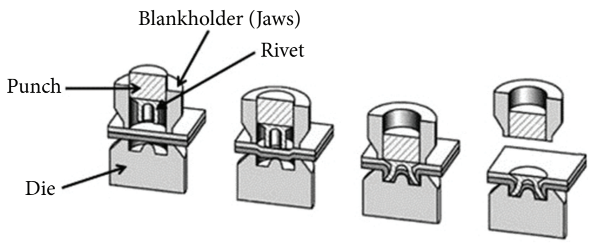


Figure 2: Self-pierce riveting operation with a semitubular rivet [26].

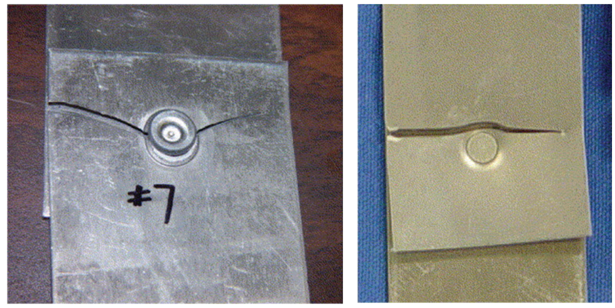
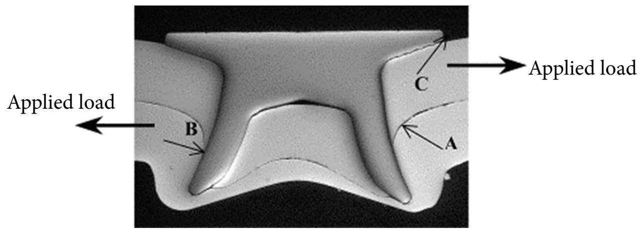


Figure 3: Typical lap-shear fatigue failure modes of SPR joints [30].



A: interface between the two riveted sheets
B: interface between the rivet shank and the locked sheet
C: interface between the edge of the rivet head and the pierced sheet

Figure 4: Three fretting positions in a SPR joint [31, 32].

than fusion, SPR can be used for a wide range of advanced materials. The principle of SPR with a semitubular rivet is given in Figure 2 [26].

The fatigue behavior of the SPR joints has been investigated by a number of authors for a number of materials. All agree that the fatigue strength of SPR joints is superior to that of the spot-welded joints.

For efficient simulations of stiffness and operational strength behavior, a node-independent SPR model was developed by Ruprechter et al. [27]. Global and local stiffness were modeled in a proper way and it is possible to determine the local stresses needed for the fatigue life estimation. In Lim's research paper [28], the simulations of various SPR specimens were performed to predict the fatigue life of SPR connections under different shape combinations. Finite element models of various SPR specimens were developed using a FEMFAT SPOT SPR preprocessor. The fatigue lives of SPR specimens were predicted using a FEMFAT 4.4e based on the linear FEA. In Di Franco et al.'s paper [29] the possibility to join aluminum alloys blanks and carbon fiber composites panels by SPR operation was considered. In particular a few case studies were carried out at the varying of the process parameters. The effectiveness of the obtained joints was tested through tensile and fatigue tests.

Sun et al.'s paper [30] summarized the fatigue test results of SPR joints between similar and dissimilar sheet metals. Fatigue test results indicated that SPR joints have superior fatigue strength than resistance spot weld (RSW) joints for the same material combinations. It was also found that different piercing directions (from thinner sheet to thicker sheet or from thicker sheet to thinner sheet) for SPR joints have a noticeable effect on the static and fatigue strength of the joints. Figure 3 shows the typical lap-shear fatigue failure modes of SPR joints.

A study was conducted by Han et al. [31] to characterize fretting fatigue in SPR single-lap joints of aluminum alloy 5754 sheets. The experimental results showed that fretting occurred at three different positions in a SPR joint, as shown in Figure 4. It was established that fretting led to surface work-hardening and crack initiation as well as early-stage crack propagation. The fretting behavior of SPR aluminum alloy joints with different interfacial conditions was investigated by Han et al. [32]. The fatigue life of the joints was observed to be dependent on the fretting behavior under different interfacial conditions, as also shown in Figure 4. They found that the presence of a wax-based solid surface lubricant on the surface of the aluminum alloy sheet could delay the onset of fretting damage.

In Wang et al.'s paper [33], a new process was presented using gunpowder to drive the SPR process. A SPR joint formed using the new process has different geometric characteristics from one created using a conventional system. The tensile-shear, cross-tension, fatigue, and impact performances of SPR joints using the new device were compared to those of spot-welded joints on aluminum sheets. The results showed that the new SPR joints have provided a similar or higher strength than resistance spot welds. Monotonic and fatigue strengths of coach peel pop rivet (CPPR) and coach peel self-piercing rivet (CPSPR) joined specimens of aluminum alloy with different plate thickness combinations were investigated by Li and Fatemi [34]. It was found that the overall fatigue performance of the CPSPR joints is better than that of the CPPR specimens with the same thickness combinations. Fatigue crack formation locations and growth paths depend on plate thickness combinations, applied load level, and load ratio for both CPPR and CPSPR joints. Min et al. [35] carried out an assessment for structural stiffness and fatigue life on self-piercing rivet of car bodies. They found that even though the structural stiffness of an SPR joint specimen is roughly the same with another type of joint, the fatigue life is different according to sheet material and its thickness. The results of numerical analysis were nearly identical to those of experiments.

Efforts have also been focused on enhancing the fatigue life of SPR joints through process optimization. Jin and Mallick [36] found that ring coining improved the fatigue life of SPR joints in aluminum alloys and the degree of improvement may be dependent on the coining condition and the sheet thickness combination. A new method combining hydroforming and SPR was proposed by Neugebauer et al. [37]. In contrast to the standard method, the riveting process was achieved without a solid die, instead high pressure fluid acted as the die during joining. Han et al. [38] reported the influence of sheet prestraining on the static and fatigue behavior of SPR aluminum alloy sheet. They concluded that the rate of increase of the static and fatigue strength differed as the prestraining levels varied. Iyer et al. [39] found both the fatigue and static strength of double-rivet SPR joints to be strongly dependent on the "orientation combination" of the rivets.

3. Mechanical Clinching

Mechanical clinching is a mechanical joint for fastening sheet metal components, and it is widely used in automotive industry. The clinching process is a method of joining sheet metal or extrusions by localized cold forming of materials. The result is an interlocking friction joint between two or more layers of material formed by a punch into a special die. Depending on the tooling sets used, clinched joints can be made with or without the need for cutting. By using a round tool type, materials are only deformed. If a square tool is used, however, both deformation and cutting of materials are required. The principle of clinching [40] is given in Figure 5.

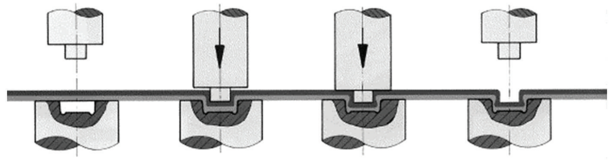


Figure 5: Principle of mechanical clinching [40].

Although the static strength of clinched joints is lower than that of other joints, the fatigue strength of clinched joints is comparable to that of other joints, and the strength of the clinched joints is more consistent with a significantly lower variation across a range of samples [3]. In Mizukoshi and Okada's study [41], tensile-shear strength and fatigue strength of riveting joints, clinching joints, and rivet-bonded joints for aluminum autobody sheets were investigated and compared with those of spot-welded joints. Moreover corrosion performances have also been investigated.

In Lin et al.'s study [42], tensile-shear tests and fatigue tests were carried out on clinched joints of 6063-T5 aluminum alloy sheet to investigate the tensile-shear strength and fatigue strength. Based on the joint strength results of clinched joint, the joint pitch of the built-up beam is designed under the specified bending load. Galtier and Duchet [43] investigated the fatigue behavior of high strength steel thin sheet assemblies. The main parameters that influence the fatigue behavior of assemblies were presented and some comparisons were made. For example, while the steel grade has a very small influence on the fatigue strength of spot welds, the riveted or clinched specimens exhibit a higher fatigue property on high strength steel than on mild steel.

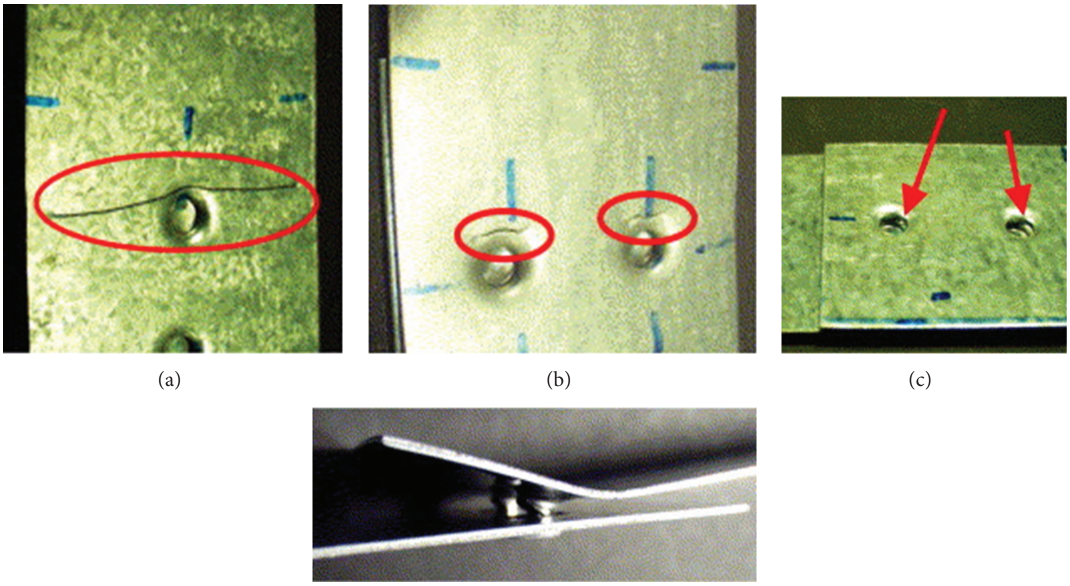
The work of Carboni et al. [44] focused on a deeper study of the mechanical behavior of clinching in terms of static, fatigue, and residual strength tests after fatigue damage. Figure 6 shows the failures observed during fatigue tests. Fractographic observations showed three different failure modes whose occurrence depends on the maximum applied load and on the stress ratio. Results were supported by FEM analyses showing that the failure regions of the clinched joints correspond to those with high stress concentrations.

Sjöström and Johansson [45] investigated residual stress relaxation during fatigue of clinched joints in stainless steels. Hahn et al. [46] carried out extended failure analysis for the case of tensile shear tests on clinched H-specimens subjected to dynamic loads, the local temperature distributions were determined during the test. They concluded that it is possible to further supplement the failure analysis during fatigue tests and to provide additional reference points for the design of components.

In Saathoff and Mallick's paper [47], the effect of die/punch combination of the static and fatigue strength of clinched joints between two aluminum alloy sheets was studied. The effect of elevated temperature exposure after the clinching operation on the static and fatigue strength of clinched joints was also examined. They found that, for the particular aluminum alloy and sheet thickness considered, the smallest punch and the smallest die ring depth combination provide the most consistent static failure load in both unpainted and painted conditions.

4. Structural Adhesive Bonding

Though adhesive bonding has been used for many centuries, it is only in the last seventy years that the science and technology of structural adhesive bonding have really progressed significantly. Structural adhesive bonding is currently used in many areas such as automobile and aerospace industries. However, in the manufacture of automobiles the adhesives are almost always used as basic sealant materials or in noncritical secondary structures. In the manufacture of aircrafts the use of adhesive bonded joints has also largely been limited to



(a) (b) (c)

(d)

Figure 6: Failures observed during fatigue tests [44]: (a) low maximum applied stress at $R = 0.1$ and $R = 0.3$, (b) high maximum applied stress at $R = 0.1$ and $R = 0.3$, (c) sometimes observed for high maximum applied stress at $R = 0.1$, and (d) all $R = 0.7$ and high maximum applied stress at $R = 0.3$.

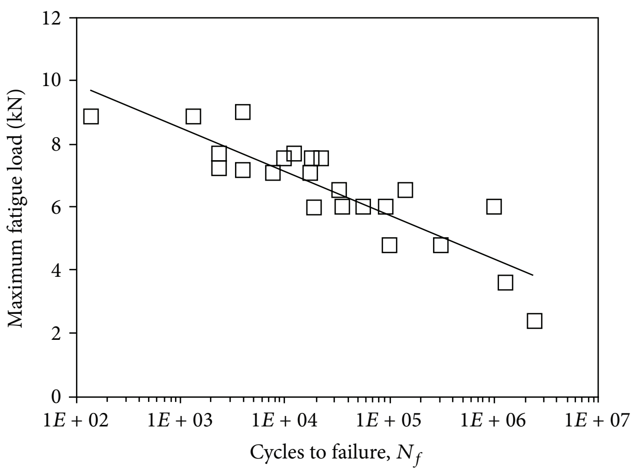


Figure 7: The L-N curve for the adhesively bonded single lap joints [49].

secondary noncritical structures such as aerodynamic fairings and wing panels. Therefore, the use of adhesives in truly structural applications has been quite limited. The reasons for these limitations are as follows [48]: (a) a concern about the fatigue and durability behavior of bonded, structural components over the expected lifetime of the vehicle, and (b) secondly, the fracture behavior of adhesive bonded joints, particularly those with dissimilar adherends, is still not well understood. In order to overcome these problems, the fatigue behavior of structural adhesively bonded joints has been the subject of a considerable amount of investigations.

For structural adhesively bonded joints, the presence of fatigue loading is found to lead to a much lower resistance to crack growth than under monotonic loading. The fatigue behavior of adhesively bonded joints needs a significant research improvement in order to understand the failure mechanisms and the influence of parameters such as surface pretreatment, adhesive thickness, or adherends thickness.

The backface strain (BFS) measurement technique was used by Shenoy et al. [49] to characterise fatigue damage in the single-lap joints (SLJs) subjected to constant amplitude fatigue loading. Different regions in the BFS plots were correlated with damage in the joints through microscopic characterization of damage and cracking in partially fatigued joints and comparison with 3D FEA of various crack growth scenarios. Figure 7 shows L-N curve for the adhesively bonded single lap joints. In a similar topic, an elastoplastic damage model was proposed by Graner Solana et al. [50] for predicting the experimentally observed backface strain patterns and fatigue life at different fatigue loads.

In Wahab et al.'s study [51], the damage parameters for crack initiation in a SLJ were determined by combining continuous damage mechanics, FEA, and experimental fatigue data. It was found that the effect of stress singularity also contributes to the complex state of stress and to the variability of the triaxiality function along the adhesive layer in a SLJ. Keller and Schollmayer [52] studied the through-thickness performance of adhesive joints between pultruded FRP bridge decks and steel girders experimentally and numerically. They concluded that the joint ultimate loads could be accurately predicted based on stress concentration factors from FEA and FRP through-thickness tensile strength values obtained from small-scale coupon tests.

In a recent study, Jen and Ko [53] investigated the effect of bonding dimensions on fatigue strength. Three selected

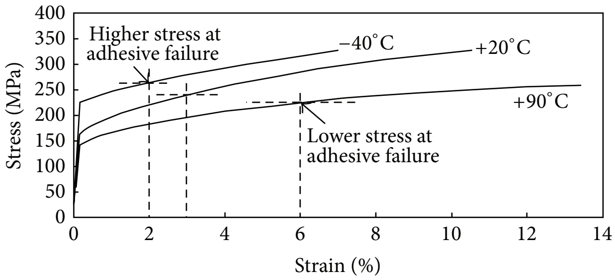


Figure 8: Stress-strain curves for sheet steel at −40, +20, and +90°C along with the adhesive strain to failure at the corresponding temperatures [61].

parameters, namely, maximum interfacial peeling stress, maximum interfacial shear stress, and a linear combination of interfacial peeling stress and shear stress, were considered to correlate with the fatigue life data of all specimens with various adhesive dimensions. A research study on the fatigue behaviour of aluminium alloy adhesive lap joints was carried out by Pereira et al. [54] to understand the effect of surface pretreatment and adherends thickness on the fatigue strength of adhesive joints. The FEA was also performed to understand the effect of the adherends thickness on the stress level.

Fessel et al.'s paper [55] assessed the fatigue performance of reverse-bent joints. Results from analysis demonstrated that significant improvements could be achieved. The propagation of an interface crack subjected to mixed mode I/II was investigated by Marannano et al. [56] for Al-Al bonded joints. The analytical strain energy release rate was compared with the FEA using the virtual crack closure technique (VCCT). Fatigue crack propagation behaviour of adhesively-bonded CFRP/aluminium joints was investigated by Ishii et al. [57]. An FEA was conducted to investigate the mode ratio, and stress and strain distributions near the crack tip.

Structural adhesives are generally thermosets such as acrylic, epoxy, polyurethane, and phenolic adhesives. The adhesion characteristics of adhesives are very sensitive to manufacturing and environmental conditions. Therefore the fatigue behavior of adhesive joints is affected by both temperature during cure and service environments.

The prediction of fatigue threshold in composite adhesively bonded joints using continuum damage mechanics (CDM) and fracture mechanics (FM) approaches was investigated at various test temperatures by Wahab et al. [58]. The stresses were calculated from nonlinear FEA, considering both geometrical and material nonlinearities. The mixed-mode fatigue fracture of intercomposite adhesive joints over a range of temperatures and solvents was studied by Arzoumanidis and Liechti [59]. Experiments were conducted on specimens that consist of swirled glass fiber/isocyanurate matrix composite adherends bonded with a urethane adhesive. Crack length was determined using compliance techniques as well as digital imaging techniques. Effect of temperature on the quasistatic strength and fatigue resistance of bonded composite double lap joints was studied by Ashcroft et al. [60]. It was seen that the multidirectional (MD) CFRP joints were stronger at low temperatures and the unidirectional (UD) CFRP joints stronger at high temperatures.

A detailed series of experiments and FEA were carried out by Grant et al. [61] to assess the effects of temperature that an automotive joint might experience in service. Tests were carried out at −40 and +90°C. It was shown that the failure criterion proposed at room temperature is still valid at low and high temperatures, the failure envelope moving up and down as the temperature increases or decreases, respectively. Figure 8 shows the stress-strain curves for sheet steel at −40, +20, and +90°C along with the adhesive strain to failure at the corresponding temperatures.

Abdel Wahab et al. studied the diffusion of moisture in adhesively bonded composite joints [62]. Both unidirectional and multidirectional composites were considered, as well as two different fillet shapes, that is, rectangular and triangular fillet. Iwasa and Hattori [63] developed an evaluation method that separates the effects of temperature on fatigue strength into two effects: thermal residual stress and low temperature. And the stress singularity parameters of the delamination edges under mechanical and thermal loadings were analyzed by FEM for various delamination lengths. In Abdel Wahab et al.'s paper [64], a procedure was outlined and programmed in software in order to predict the fatigue threshold in composite adhesively bonded joints. The theory of continuum damage mechanics has been used to develop damage evolution laws for unidirectional double lap joints at different temperatures.

5. Hybrid Joints

It is also important for one joining process to benefit from the advantages of other fastening techniques. These can be done by combining one joining process with other fastening techniques and are referred to as hybrid-fastening processes. A number of researchers have carried out fatigue performances of the hybrid joints in different materials with various load conditions. Their study shows that the combination produced a much stronger joint in fatigue tests.

Using ADINA FEA code, a computational model was established by Chang et al. [65] for studying the stress distribution and fatigue behavior of weld-bonded lap shear joints. Both material non-linearity and geometrical non-linearity from large strain and large displacement were considered in this computation.

Fu and Mallick [66] presented a study on the static and fatigue performance of adhesive/bolted hybrid joints in a structural reaction injection molded (SRIM) composites. FEA of adhesive joints showed that the presence of lateral clamping can significantly reduce the maximum peel stress at the adhesive-substrate interface. Balanced single-lap bonded and bolt-bonded hybrid joints with flexible adhesives were studied by Hoang-Ngoc and Paroissien [67] using the FEA. Flexible adhesives were modelled using hyperelastic Mooney-Rivlin potentials. Numerical analyses of bolt-bonded hybrid joints showed that their fatigue life is longer than corresponding bolted joints. Kelly [68] investigated quasistatic strength and fatigue life of bolt-bonded hybrid composite SLJs. A 3D FEA of the hybrid joint was carried out using

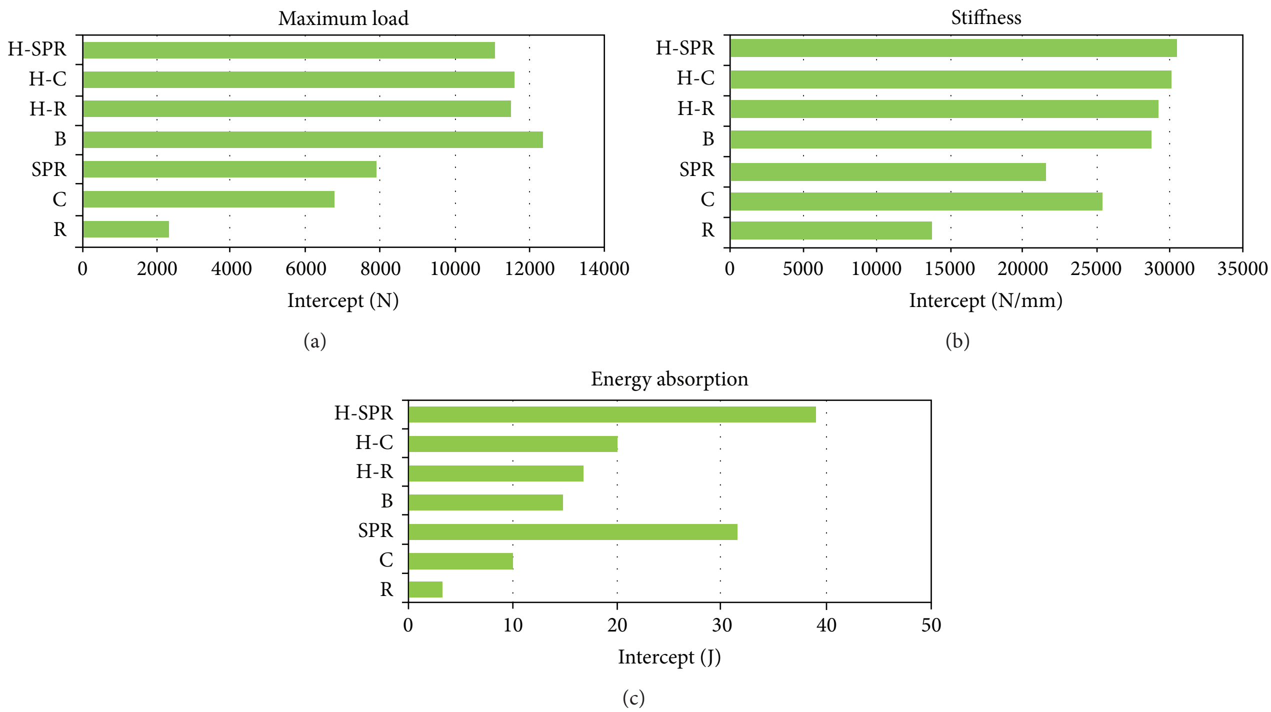


Figure 9: Intercepts of (a) strength, (b) stiffness, and (c) energy absorption for the heterogeneous joints case [75].

the ABAQUS code with the model including the effects of large-deformations, bolt-hole contact and nonlinear adhesive material properties. Three distinct stages in the fatigue life of the hybrid joints were observed where the adhesive, the bolt and their combination were all contributing to the load transfer.

Using FEA along with thin adhesive layer analysis (TALA), Fongsamootr et al. [69] carried out a parametric study of combined adhesive-riveted lap joints. The FEA/TALA results were used to predict the fatigue life of the joints as functions of the three parameters. The results showed that the maximum tensile stress is smaller with a smaller panel thickness. The results also showed that the stress concentration factor in the joints was reduced when the stiffness of the adhesive layer was increased or when the thickness of the adhesive layer was decreased. In Kunc et al.'s work [70], three joining methods were evaluated including riveting, adhesive bonding, and combination of riveting and adhesive bonding. FEA was used to predict the behavior of the structure up to the point of damage in the composite. A general method was devised by Dechwayukul et al. [71] for determining the effects of thin layers of sealants or adhesives on the mechanical behavior of riveted lap joints using FEA. The analyses revealed that adhesive layers introduce large increases in the in- and out-of-plane displacements, reduce bending and stress concentration factors (SCF), and increase the fatigue life of riveted lap joints. A 3D FE model of the riveting process was simulated by Atre and Johnson [72] to determine the effects of interference and sealant on the induced stresses. Both implicit and explicit FE techniques were utilized to model the process.

Chernenkoff's paper [73] discussed a fatigue evaluation of single overlap joints using four structural adhesives and five steels tested in laboratory ambient, elevated temperature/humidity, and corrosive environments. Weld-bonded, adhesive-bonded, mechanically joined (clinched), and spot weld data were compared. Results showed that the bonding process can improve long life fatigue strength as much as 500% compared to spot-welded joints. Improvements were less when the specimens were subjected to the last two environments.

In Moroni and Pirondi's work [74] an extensive experimental campaign was carried out in order to compare the strength of different hybrid joints with that of the related nonhybrid joints, evaluating also the influence of geometrical and environmental factors. In a recent study, Moroni et al. [75] carried out experimental analysis and comparison of the strength of simple and hybrid structural joints. The experimental analysis was conducted using the design of experiments (DoE) methodology and the influence of the material, geometrical factors and environment on static and fatigue strength, stiffness and energy absorption was assessed through the analysis of variance (ANOVA). Hybrid and simple joints were then compared in terms of mechanical response under the various conditions tested. Figure 9 shows the intercepts of strength, stiffness, and energy absorption for the heterogeneous joints case.

6. Conclusion

Almost every mechanical structure requires component members to be jointed. Some relative new fastening techniques such as SPR, mechanical clinching and structural adhesive bonding are efficient joining methods which are suitable for joining advanced lightweight sheet materials that are hard to weld; especially SPR, mechanical clinching, structural adhesive bonding, and their combinations are extensively used in lightweight car industry recent years for joining various materials in the assembly of components and structures. SPR is normally used in main load-bearing structures whereas mechanical clinching used in secondary load-bearing structures. Adhesively bonding is usually used to increase the strength of mechanical joints and make them watertight. It is commonly understood that the addition of adhesive in SPR or clinched joints is beneficial, but it is not clear if there are negative effects on mechanical properties of the joints [76]. Thus adequate understanding of fatigue behavior of the fastening joints is necessary to ensure efficiency, safety, and reliability of such joints. The recent development in fatigue behavior analysis of the fastening joints is described with particular reference to some major factors that influence the fatigue behavior of the fastening joints: failure mechanism, environmental effects and hybrid joining techniques. FEA of fatigue behavior of the fastening joints will allow many different fatigue failure processes to be simulated in order to perform a selection of different parameters before testing, which would be very time-consuming or prohibitively expensive in practice. The main methods used in FEA of fatigue behavior of the fastening joints, such as parameters selection, materials modeling, and meshing procedure, are discussed and illustrated with brief case studies from the literature. The references presented in this paper are by no means complete but they give a comprehensive representation of some general trends on the subjects.

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References

[1] X. He, F. Gu, and A. Ball, "Recent development in finite element analysis of self-piercing riveted joints," *International Journal of Advanced Manufacturing Technology*, vol. 58, no. 5–8, pp. 643–649, 2012.

[2] X. He, I. Pearson, and K. Young, "Self-pierce riveting for sheet materials: state of the art," *Journal of Materials Processing Technology*, vol. 199, no. 1, pp. 27–36, 2008.

[3] X. He, "Recent development in finite element analysis of clinched joints," *International Journal of Advanced Manufacturing Technology*, vol. 48, no. 5–8, pp. 607–612, 2010.

[4] X. He, "A review of finite element analysis of adhesively bonded joints," *International Journal of Adhesion and Adhesives*, vol. 31, no. 4, pp. 248–264, 2011.

[5] X. He, *Static and dynamic analysis of single lap-jointed cantilevered beams [Ph.D. dissertation]*, University of Manchester, Manchester, UK, 2003.

[6] V. Shenoy, I. A. Ashcroft, G. W. Critchlow, and A. D. Crocombe, "Unified methodology for the prediction of the fatigue behaviour of adhesively bonded joints," *International Journal of Fatigue*, vol. 32, no. 8, pp. 1278–1288, 2010.

[7] H. Hosseini-Toudeshky, M. Saber, and B. Mohammadi, "Finite element crack propagation of adhesively bonded repaired panels in general mixed-mode conditions," *Finite Elements in Analysis and Design*, vol. 45, no. 2, pp. 94–103, 2009.

[8] D. P. Romilly and R. J. Clark, "Elastic analysis of hybrid bonded joints and bonded composite repairs," *Composite Structures*, vol. 82, no. 4, pp. 563–576, 2008.

[9] H. R. Ghorbani and J. K. Spelt, "Analytical elasto-creep model of interfacial thermal stresses and strains in trilayer assemblies," *International Journal of Solids and Structures*, vol. 43, no. 25-26, pp. 7424–7449, 2006.

[10] M. Quaresimin and M. Ricotta, "Stress intensity factors and strain energy release rates in single lap bonded joints in composite materials," *Composites Science and Technology*, vol. 66, no. 5, pp. 647–656, 2006.

[11] M. M. Abdel Wahab, I. A. Ashcroft, A. D. Crocombe, and P. A. Smith, "Finite element prediction of fatigue crack propagation lifetime in composite bonded joints," *Composites A*, vol. 35, no. 2, pp. 213–222, 2004.

[12] H. Hadavinia, A. J. Kinloch, M. S. G. Little, and A. C. Taylor, "The prediction of crack growth in bonded joints under cyclic-fatigue loading II. Analytical and finite element studies," *International Journal of Adhesion and Adhesives*, vol. 23, no. 6, pp. 463–471, 2003.

[13] M. M. Abdel Wahab, I. A. Ashcroft, A. D. Crocombe, and P. A. Smith, "Fatigue crack propagation in adhesively bonded joints," *Key Engineering Materials*, vol. 251-252, pp. 229–233, 2003.

[14] D. M. Hoyt, S. H. Ward, and P. J. Minguet, "Strength and fatigue life modeling of bonded joints in composite structure," *Journal of Composites Technology and Research*, vol. 24, no. 3, pp. 188–208, 2002.

[15] M. Imanaka, T. Turui, and Y. Akizuki, "Evolution of damage zone in adhesive layer of adhesively bonded butt joints under cyclic loading," *Polymers and Polymer Composites*, vol. 9, no. 6, pp. 385–392, 2001.

[16] V. V. Silberschmidt, J. P. Casas-Rodriguez, and I. A. Ashcroft, "Impact fatigue of adhesive joints," *Key Engineering Materials*, vol. 399, pp. 71–78, 2009.

[17] J. Wang, A. N. Rider, M. Heller, and R. Kaye, "Theoretical and experimental research into optimal edge taper of bonded repair patches subject to fatigue loadings," *International Journal of Adhesion and Adhesives*, vol. 25, no. 5, pp. 410–426, 2005.

[18] P. T. Cheuk, L. Tong, A. N. Rider, and J. Wang, "Analysis of energy release rate for fatigue cracked metal-to-metal double-lap shear joints," *International Journal of Adhesion and Adhesives*, vol. 25, no. 2, pp. 181–191, 2005.

[19] H. Y. Hwang, B. J. Kim, W. S. Chin, H. S. Kim, and D. G. Lee, "Prediction of crack length and crack growth rate of adhesive joints by a piezoelectric method," *Journal of Adhesion Science and Technology*, vol. 19, no. 12, pp. 1081–1111, 2005.

[20] J. M. Ferreira, H. Silva, J. D. Costa, and M. Richardson, "Stress analysis of lap joints involving natural fibre reinforced interface layers," *Composites B*, vol. 36, no. 1, pp. 1–7, 2005.

[21] P. T. Cheuk, L. Tong, C. H. Wang, A. Baker, and P. Chalkley, "Fatigue crack growth in adhesively bonded composite-metal double-lap joints," *Composite Structures*, vol. 57, no. 1–4, pp. 109–115, 2002.

[22] A. D. Crocombe, C. Y. Ong, C. M. Chan, M. M. Abdel Wahab, and I. A. Ashcroft, "Investigating fatigue damage evolution in adhesively bonded structures using backface strain measurement," *Journal of Adhesion*, vol. 78, no. 9, pp. 745–776, 2002.

[23] M. M. Abdel Wahab, I. A. Ashcroft, A. D. Crocombe, and P. A. Smith, "Numerical prediction of fatigue crack propagation lifetime in adhesively bonded structures," *International Journal of Fatigue*, vol. 24, no. 6, pp. 705–709, 2002.

[24] R. Jones, A. Kotousov, and I. H. Marshall, "Adhesively bonded joints under cyclic loading spectra," *Fatigue and Fracture of Engineering Materials and Structures*, vol. 25, no. 2, pp. 173–185, 2002.

[25] W. Cai, P. C. Wang, and W. Yang, "Assembly dimensional prediction for self-piercing riveted aluminum panels," *International Journal of Machine Tools and Manufacture*, vol. 45, no. 6, pp. 695–704, 2005.

[26] P. Johnson, J. D. Cullen, L. Sharples, A. Shaw, and A. I. Al-Shamma'a, "Online visual measurement of self-pierce riveting systems to help determine the quality of the mechanical interlock," *Measurement*, vol. 42, no. 5, pp. 661–667, 2009.

[27] F. Ruprechter, G. Kepplinger, N. Dölle, M. Martin, and C. Ageorges, "Fatigue life estimation of self piercing rivets in car body development based on local stresses using node independent meshing," *VDI Berichte*, no. 1967, pp. 777–795, 2006 (German).

[28] B. K. Lim, "Analysis of fatigue life of SPR (Self-Piercing Riveting) jointed various specimens using FEM," *Materials Science Forum*, vol. 580-582, pp. 617–620, 2008.

[29] G. Di Franco, L. Fratini, A. Pasta, and V. F. Ruisi, "On the self-piercing riveting of aluminium blanks and carbon fibre composite panels," *International Journal of Material Forming*, vol. 3, no. 1, pp. 1035–1038, 2010.

[30] X. Sun, E. V. Stephens, and M. A. Khaleel, "Fatigue behaviors of self-piercing rivets joining similar and dissimilar sheet metals," *International Journal of Fatigue*, vol. 29, no. 2, pp. 370–386, 2007.

[31] L. Han, A. Chrysanthou, K. W. Young, and J. M. O'Sullivan, "Characterization of fretting fatigue in self-piercing riveted aluminium alloy sheets," *Fatigue and Fracture of Engineering Materials and Structures*, vol. 29, no. 8, pp. 646–654, 2006.

[32] L. Han, A. Chrysanthou, and J. M. O'Sullivan, "Fretting behaviour of self-piercing riveted aluminium alloy joints under different interfacial conditions," *Materials and Design*, vol. 27, no. 3, pp. 200–208, 2006.

[33] B. Wang, C. Hao, J. Zhang, and H. Zhang, "A new self-piercing riveting process and strength evaluation," *Journal of Manufacturing Science and Engineering*, vol. 128, no. 2, pp. 580–587, 2006.

[34] B. Li and A. Fatemi, "An experimental investigation of deformation and fatigue behavior of coach peel riveted joints," *International Journal of Fatigue*, vol. 28, no. 1, pp. 9–18, 2006.

[35] G. K. Min, H. K. Jin, C. L. Kun, and Y. Won, "Assessment for structural stiffness and fatigue life on self-piercing rivet of car bodies," *Key Engineering Materials*, vol. 297–300, pp. 2519–2524, 2005.

[36] Z. Jin and P. K. Mallick, "Enhancement of fatigue life of self-piercing riveted joints by coining," in *Proceedings of the ASME International Mechanical Engineering Congress and Exposition (IMECE '02)*, pp. 417–430, November 2002.

[37] R. Neugebauer, R. Mauermann, and R. Grützner, "Combination of hydroforming and joining," *Steel Research International*, vol. 76, no. 12, pp. 939–944, 2005.

[38] L. Han, K. W. Young, A. Chrysanthou, and J. M. O'Sullivan, "The effect of pre-straining on the mechanical behaviour of self-piercing riveted aluminium alloy sheets," *Materials and Design*, vol. 27, no. 10, pp. 1108–1113, 2006.

[39] K. Iyer, S. J. Hu, F. L. Brittman, P. C. Wang, D. B. Hayden, and S. P. Marin, "Fatigue of single- and double-rivet self-piercing riveted lap joints," *Fatigue and Fracture of Engineering Materials and Structures*, vol. 28, no. 11, pp. 997–1007, 2005.

[40] J. Varis, "Ensuring the integrity in clinching process," *Journal of Materials Processing Technology*, vol. 174, no. 1-3, pp. 277–285, 2006.

[41] H. Mizukoshi and H. Okada, "Fatigue properties of mechanical fastening joints," *Materials Science Forum*, vol. 242, pp. 231–238, 1997.

[42] P. Lin, K. Komatsu, and K. Kokubo, "Study of built-up aluminum beam connected by mechanical clinching," *Transactions of the Japan Society of Mechanical Engineers A*, vol. 76, no. 763, pp. 317–324, 2010 (Japanese).

[43] A. Galtier and M. Duchet, "Fatigue behaviour of high strength steel thin sheet assemblies," *Welding in the World*, vol. 51, no. 3-4, pp. 19–27, 2007.

[44] M. Carboni, S. Beretta, and M. Monno, "Fatigue behaviour of tensile-shear loaded clinched joints," *Engineering Fracture Mechanics*, vol. 73, no. 2, pp. 178–190, 2006.

[45] P. Sjöström and S. Å. H. Johansson, "Residual stress relaxation during fatigue of clinched joints in stainless steels," *Materials Science Forum*, vol. 490-491, pp. 404–408, 2005.

[46] O. Hahn, Y. Tan, and M. Oeter, "Extended failure analysis of clinching elements in multi-spot joints subjected to cyclic loads," *Schweissen und Schneiden/Welding and Cutting*, vol. 55, no. 5, pp. 262–267, 2003.

[47] D. G. Saathoff and P. K. Mallick, "Static and fatigue strength evaluation of clinched joints in an aluminum alloy," in *Proceedings of the SAE International Congress & Exposition*, pp. 77–83, February 1998.

[48] A. Baldan, "Adhesively-bonded joints in metallic alloys, polymers and composite materials: mechanical and environmental durability performance," *Journal of Materials Science*, vol. 39, no. 15, pp. 4729–4797, 2004.

[49] V. Shenoy, I. A. Ashcroft, G. W. Critchlow, A. D. Crocombe, and M. M. Abdel Wahab, "An investigation into the crack initiation and propagation behaviour of bonded single-lap joints using backface strain," *International Journal of Adhesion and Adhesives*, vol. 29, no. 4, pp. 361–371, 2009.

[50] A. Graner Solana, A. D. Crocombe, and I. A. Ashcroft, "Fatigue life and backface strain predictions in adhesively bonded joints," *International Journal of Adhesion and Adhesives*, vol. 30, no. 1, pp. 36–42, 2010.

[51] M. M. Abdel Wahab, I. Hilmy, I. A. Ashcroft, and A. D. Crocombe, "Evaluation of fatigue damage in adhesive bonding—part 2: single lap joint," *Journal of Adhesion Science and Technology*, vol. 24, no. 2, pp. 325–345, 2010.

[52] T. Keller and M. Schollmayer, "Through-thickness performance of adhesive joints between FRP bridge decks and steel girders," *Composite Structures*, vol. 87, no. 3, pp. 232–241, 2009.

[53] Y.-M. Jen and C.-W. Ko, "Evaluation of fatigue life of adhesively bonded aluminum single-lap joints using interfacial parameters," *International Journal of Fatigue*, vol. 32, no. 2, pp. 330–340, 2010.

[54] A. M. Pereira, J. M. Ferreira, F. V. Antunes, and P. J. Bártolo, "Study on the fatigue strength of AA 6082-T6 adhesive lap joints," *International Journal of Adhesion and Adhesives*, vol. 29, no. 6, pp. 633–638, 2009.

[55] G. Fessel, J. G. Broughton, N. A. Fellows, J. F. Durodola, and A. R. Hutchinson, "Fatigue performance of metallic reverse-bent joints," *Fatigue and Fracture of Engineering Materials and Structures*, vol. 32, no. 9, pp. 704–712, 2009.

[56] G. V. Marannano, L. Mistretta, A. Cirello, and S. Pasta, "Crack growth analysis at adhesive-adherent interface in bonded joints under mixed mode I/II," *Engineering Fracture Mechanics*, vol. 75, no. 18, pp. 5122–5133, 2008.

[57] K. Ishii, M. Imanaka, and H. Nakayama, "Fatigue crack propagation behavior of adhesively-bonded CFRP/aluminum joints," *Journal of Adhesion Science and Technology*, vol. 21, no. 2, pp. 153–167, 2007.

[58] M. M. Abdel Wahab, I. A. Ashcroft, A. D. Crocombe, and A. D. Crocombe, "Prediction of fatigue thresholds in adhesively bonded joints using damage mechanics and fracture mechanics," *Journal of Adhesion Science and Technology*, vol. 15, no. 7, pp. 763–781, 2001.

[59] G. A. Arzoumanidis and K. M. Liechti, "Mixed-mode fatigue fracture of adhesive joints in harsh environments," in *Proceedings of the 42nd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference*, pp. 782–785, April 2001.

[60] I. A. Ashcroft, D. J. Hughes, S. J. Shaw, M. Abdel Wahab, and A. Crocombe, "Effect of temperature on the quasi-static strength and fatigue resistance of bonded composite double lap joints," *Journal of Adhesion*, vol. 75, no. 1, pp. 61–88, 2001.

[61] L. D. R. Grant, R. D. Adams, and L. F. M. da Silva, "Effect of the temperature on the strength of adhesively bonded single lap and T joints for the automotive industry," *International Journal of Adhesion and Adhesives*, vol. 29, no. 5, pp. 535–542, 2009.

[62] M. M. Abdel Wahab, I. A. Ashcroft, A. D. Crocombe, and S. J. Shaw, "Diffusion of moisture in adhesively bonded joints," *Journal of Adhesion*, vol. 77, no. 1, pp. 43–80, 2001.

[63] M. Iwasa and T. Hattori, "Evaluation method for fatigue strength of FRP/metal adhesive joints considering mean stress," *Journal of Engineering Materials and Technology*, vol. 125, no. 4, pp. 402–405, 2003.

[64] M. M. Abdel Wahab, I. A. Ashcroft, A. D. Crocombe, and L. Joussot, "Lifetime prediction for fatigue damage in bonded joints," *Key Engineering Materials*, vol. 245-346, pp. 43–50, 2003.

[65] B. Chang, Y. Shi, and L. Lu, "Studies on the stress distribution and fatigue behavior of weld-bonded lap shear joints," *Journal of Materials Processing Technology*, vol. 108, no. 3, pp. 307–313, 2001.

[66] M. Fu and P. K. Mallick, "Fatigue of hybrid (adhesive/bolted) joints in SRIM composites," *International Journal of Adhesion and Adhesives*, vol. 21, no. 2, pp. 145–149, 2001.

[67] C.-T. Hoang-Ngoc and E. Paroissien, "Simulation of single-lap bonded and hybrid (bolted/bonded) joints with flexible adhesive," *International Journal of Adhesion and Adhesives*, vol. 30, no. 3, pp. 117–129, 2010.

[68] G. Kelly, "Quasi-static strength and fatigue life of hybrid (bonded/bolted) composite single-lap joints," *Composite Structures*, vol. 72, no. 1, pp. 119–129, 2006.

[69] T. Fongsamootr, C. Dechwayukul, N. Kamnerdtong, C. A. Rubin, and G. T. Hahn, "Parametric study of combined adhesive-riveted lap joints," *Key Engineering Materials*, vol. 261-263, no. 1, pp. 399–404, 2004.

[70] V. Kunc, D. Erdman, and L. Klett, "Hybrid joining in automotive applications," in *Proceedings of the International SAMPE Technical Conference*, pp. 3943–3956, May 2004.

[71] C. Dechwayukul, C. A. Rubin, and G. T. Hahn, "Analysis of the effects of thin sealant layers in aircraft structural joints," *AIAA Journal*, vol. 41, no. 11, pp. 2216–2228, 2003.

[72] A. Atre and W. S. Johnson, "Analysis of the effects of interference and sealant on riveted lap joints," *Journal of Aircraft*, vol. 44, no. 2, pp. 353–364, 2007.

[73] R. A. Chernenkoff, "Fatigue evaluation of single overlap bonded joints," in *Proceedings of the 21st International SAMPE Technical Conference*, pp. 57–71, September 1989.

[74] F. Moroni and A. Pirondi, "Hybrid joints: evaluation of the increase of the mechanical performances with respect to simple joints," *Rivista Italiana della Saldatura*, vol. 61, no. 5, pp. 603–612, 2009.

[75] F. Moroni, A. Pirondi, and F. Kleiner, "Experimental analysis and comparison of the strength of simple and hybrid structural joints," *International Journal of Adhesion and Adhesives*, vol. 30, no. 5, pp. 367–379, 2010.

[76] X. He, B. Xing, K. Zeng, F. Gu, and A. Ball, "Numerical and experimental investigations of self-piercing riveting," *The International Journal of Advanced Manufacturing Technology*, 2013.