

# FATIGUE BEHAVIOUR OF CLINCHED JOINTS

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## Abstract

The last years have seen the development of a new generation of industrial interesting mechanical joining techniques for thin sheets such as self piercing riveting, clinching, friction stir welding and laser welding. The present work concentrates on fatigue behaviour of joints obtained by clinching, a cold welding technology for thin sheets which is quickly developing in automobile, electronic and white goods industries, even if mainly in terms of static properties. The activity firstly dealt with fatigue tests and fractographic observations which evidenced different failure modes at different stress ratios. Results were then supported by FEM analyses of the clinched joints.

## Introduction

Lightweight structures and high productive rate are two of the main goals for automotive, electronic and white goods industries. The last years have seen the development, as an answer to the drawbacks of the more traditional spot welding, of a new generation of industrial interesting mechanical joining techniques for thin sheets (Barnes and Pashby [1, 2]), such as self piercing riveting, clinching, friction stir welding and laser welding. For some of this new technologies, mechanical studies are present in literature (as an example for self piercing riveting see Fu and Mallick [3]), but for others not. From this point of view, the present work concentrates on fatigue behaviour of clinching, a cold welding technology for thin sheets which is quickly developing in the industries mentioned above (Fig.1).



FIGURE 1. Clinching in automotive industry.

Clinching technology allows to join two or more metal sheets (of the same or different material, up to a total joint thickness of about 5÷6 mm), whatever their surface condition is (painted, lubricated, coated or oxidised) and without any edge preparation. After the joint has been made, there is no need for repainting the sheets or performing stress relieving treatments. The joint is made by a punch (Fig. 2a) which, penetrating in a die, forces a slip in the sheets and the formation of the local permanent set (indentation), as shown in Fig.

2b. The tools are designed in order to create an undercut which guarantees the mechanical interlock between the sheets. One of the main features of the clinching process is the absence of thermal flow during the joint making, avoiding residual stresses induced by thermal distortion and also grain flaws, such as coarsening. Compared to other joining techniques, clinching is a fast process, easy to automate, and so particularly suited when high productivity is needed; moreover, since no welding material is used, there are no supply or storage costs and chemical contamination of the joint is lower. The absence of fumes, emissions or high currents also ensures high safety for the operator and a low environmental impact. Finally, the quality of the joint can be investigated with simple non destructive geometric checks of the indentation, like indentation bottom thickness measurement. Drawbacks of this technology can be found in the fact that the maximum thickness that can be welded is 6 mm and that the maximum thickness for the single involved sheet is 3 mm. Furthermore, during the process both the faces of the joint must be free in order to apply the technology to the component. From the structural point of view, it's interesting to note (see Fig. 2b) that the sheets thickness in the button neck can become very thin respect to the original one: this is an important consideration (Bini *et al.* [4]) for the shear strength against loads acting in the plane of the sheets.

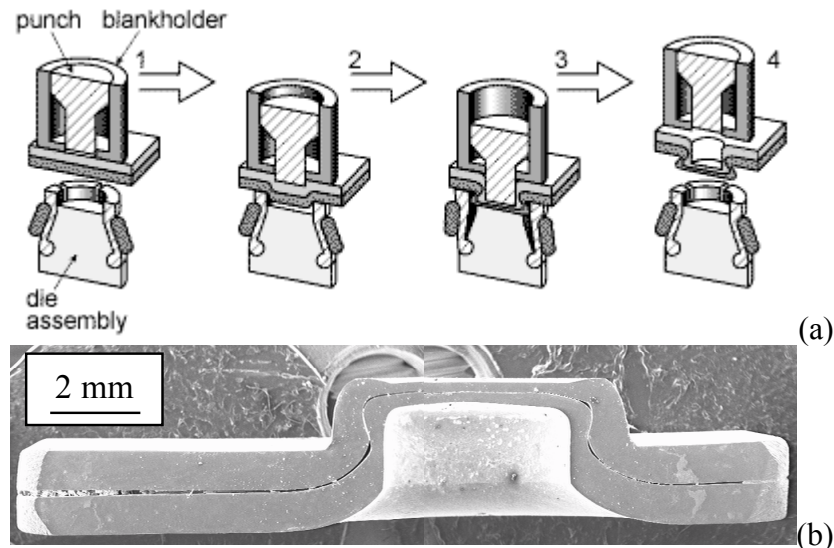


FIGURE 2. Schematic representation of the clinching process: a) technological process; b) section of a “clinched point” showing the indentation.

### Experimental set-up and results

In order to analyse the mechanical behaviour of clinched joints, specimens consisting of two thin sheets (150x50x1 mm) made in FePO2 steel were considered. Particularly (Fig. 3): i) the superimposed area of the top and bottom substrates is 50x50 mm; ii) the position of the indentations was symmetrical in respect of the specimen axis; iii) the distance between the indentation points was equal to 22 mm. Transverse joints and longitudinal joints were analysed in order to investigate the influence of load direction on strength of joints. All the indentations were realised using the same tools and pressing force equal to 40 kN. Specimens were subjected to tensile tests and fatigue tests at different stress ratios by means of an INSTRON8501 uni-axial servo-hydraulic facility (maximum nominal load

100 kN). All the specimens were equipped in the grip zone with dummy plates of thickness equal to 1 mm in order to minimise bending effects during the tests. Fatigue tests were carried out at stress ratio equal to 0.1, 0.3 and 0.7 and at a frequency equal to 50 Hz. Run-out specimens were defined at  $2 \times 10^7$  cycles.

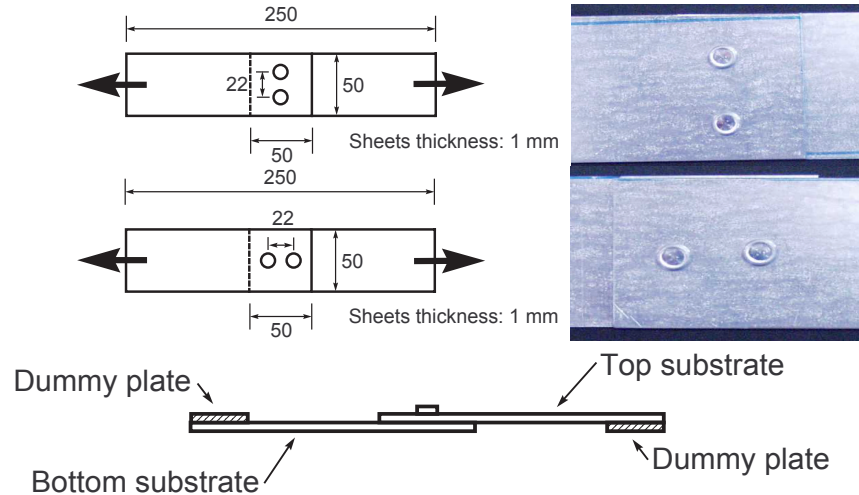


FIGURE 3. Experimental tests on transverse and longitudinal clinching indentations.

### Tensile tests

Tensile tests have been executed under displacement control conditions on both specimen configurations in order to characterise static behaviour of joints and estimate the ultimate tensile strength. Three transverse and two longitudinal specimens were considered. Fig. 4a shows the obtained load-displacement curves, while Fig. 4b the way all the tested specimen have failed. It's necessary to add that displacement values are relative to the mobile cross member of the facility and so they do not represent a pure characteristic of the clinching point.

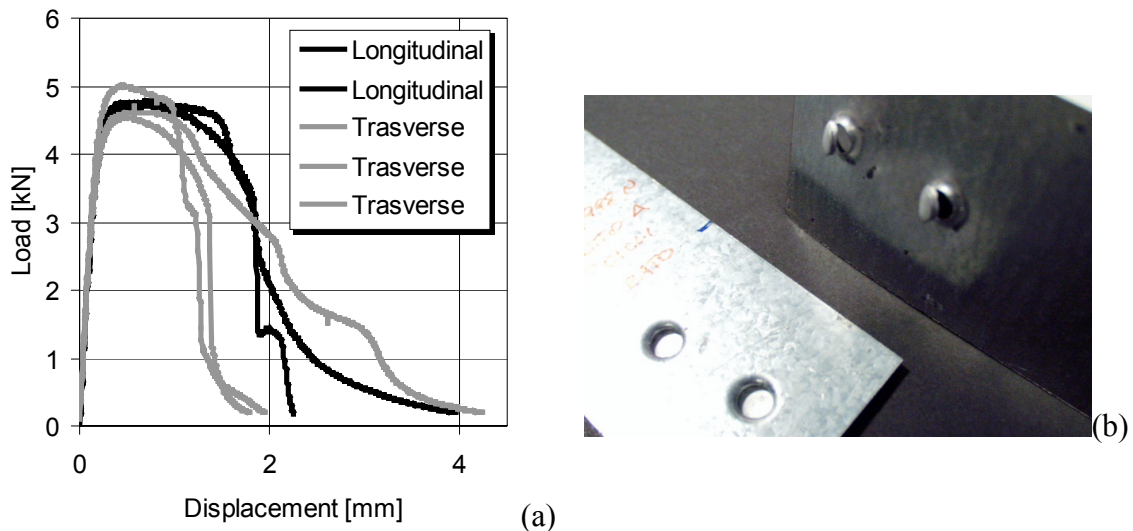


FIGURE 4. Tensile tests results: a) obtained monotonic curves; b) typical static failures with shear rupture of clinched buttons.

It seems that the ultimate stress is not dependent on joint configuration: a statistical analysis of the whole sample produced a mean value equal to 4.75 kN and a standard deviation of 0.16 kN. Furthermore, also the curves shape are very similar: a macroscopic ductile behaviour can be seen for both the two different joints and the Young's Modulus is very similar for all the tested specimens.

### Fatigue tests

Fatigue tests have been carried out in order to define and to compare S-N curves. In general, given the applied maximum load during a single test, a specimen was considered broken when the displacement of the mobile cross member of the testing machine was 0.5 mm higher than the one occurring in static tensile test performed with the same maximum load. Figs. 5a and 5b show the S-N curves obtained for the two indentation configurations in terms of applied load range.

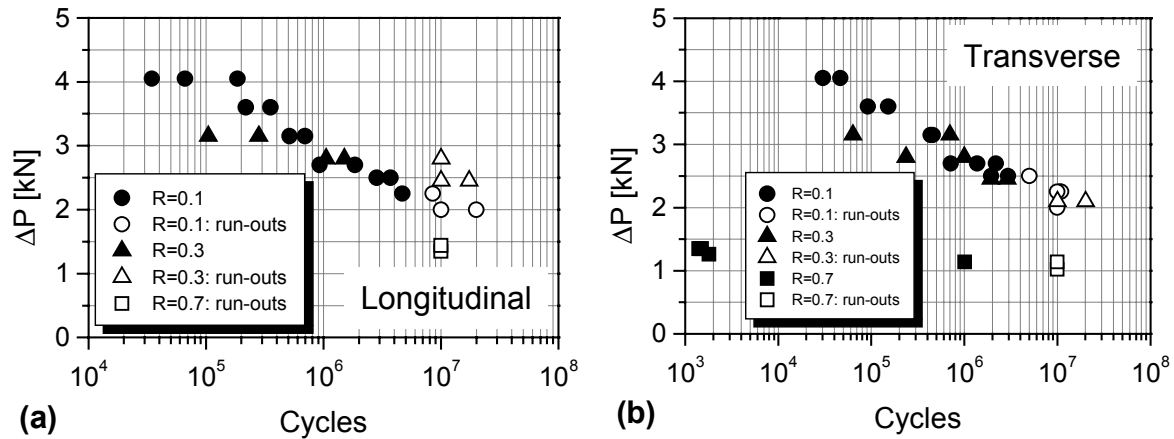


FIGURE 5. S-N curves obtained by means of fatigue tests.

It is possible to see that experimental data obtained at  $R=0.1$  and  $R=0.3$  for the two different joint configurations are well mixed and so it's possible to conclude that the joint configuration has not a significant influence on the fatigue behaviour of clinched joints. Furthermore, the fatigue limit for  $R=0.1$  and  $R=0.3$  is also very similar ( $\Delta P_{lim}=2.25\div 2.5\text{kN}$ ) and equal to about 50% of the obtained ultimate stress, a percentage significantly higher than the typical one in spot welding (i.e. 30÷40%, Satoh *et al.* [5]). In the case of  $R=0.7$ , fatigue limit is quite different from the other considered  $R$  values, suggesting that for high mean stresses a different failure mechanism takes place. This fact is supported by the observation of different macroscopic failure modes as shown in Fig. 6. Particularly, Fig. 6a failures have always been observed on the bottom substrate and at the indentation point nearer to load application, in the case of longitudinal joints, or at both the indentation points, in the case of transverse joints. Furthermore, these failures could be seen for both kind of indentation configurations when low mean stresses (i. e.  $R=0.1$  and  $R=0.3$ ) and low maximum loads were applied. Fig. 6b shows a failure occurred for the same case of Fig. 6a, but under high maximum applied loads. This difference can explain why the crack had no possibility to propagate. Fig. 6c failures have sometimes been observed at  $R=0.1$  and high maximum applied load. They are characterised by a crack nucleation and propagation along the indentation neck. Finally, Fig. 6d failures have been observed on all the broken

R=0.7 specimens and on some of R=0.3 at high maximum applied loads. This kind of failure is characterised by a disassembly of the joint sometimes due to the nucleation and propagation of a crack along the indentation neck, sometimes without any crack like during tensile tests.

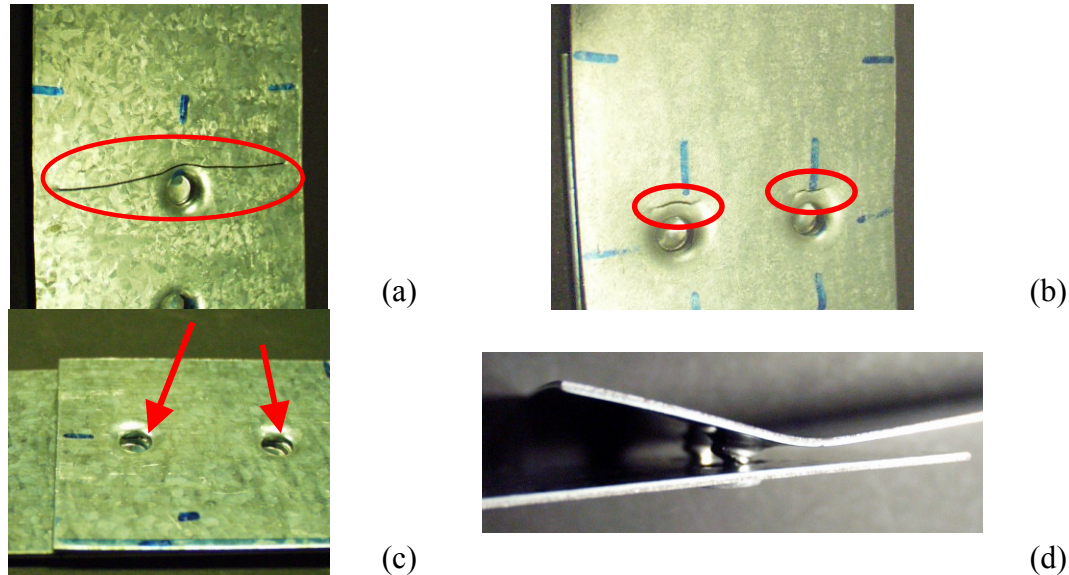


FIGURE 6. Failures observed during fatigue tests: a) low maximum applied stress at R=0.1 and R=0.3; b) high maximum applied stress at R=0.1 and R=0.3; c) sometimes observed for high maximum applied stress at R=0.1; d) all R=0.7 and high maximum applied stress at R=0.3

It's interesting also the comparison of the  $P_{\max}$  vs. R curves shown in Fig. 7: it's possible to note that increasing the R value the curves tend to be more and more flat. In the case of longitudinal joints, approaching R=0.7 the fatigue region almost disappears and run-out specimens are very near to tensile ultimate strength. Different is the case of transverse joints, where at R=0.7 the simple joint configuration does not prevent the disassembly of the clinched buttons under cyclic loads.

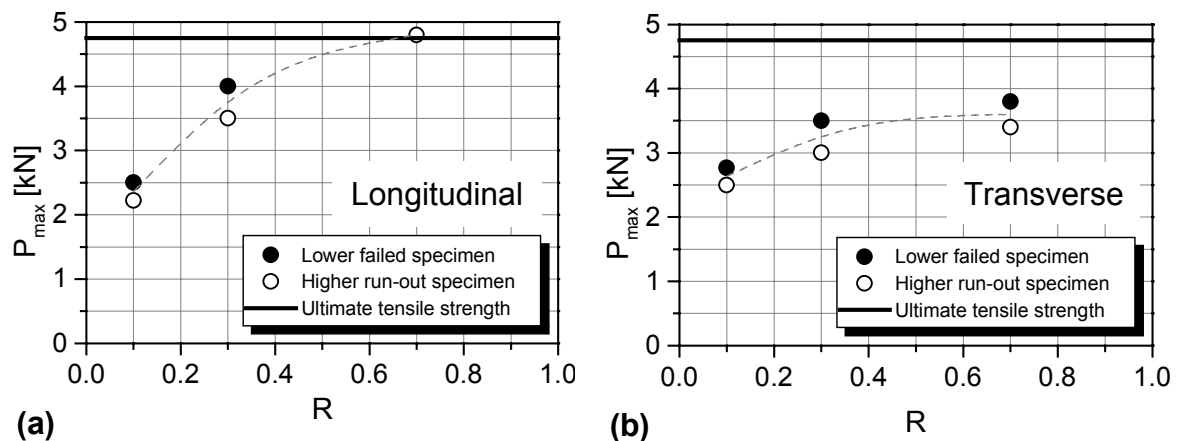


FIGURE 7.  $P_{\max}$  vs. R curves.

## Fractography

All the specimens failed at stress ratio equal to 0.1 and 0.3 were observed by means of a scan electron microscope. Firstly, it was possible to understand that crack nucleation takes place in the contact region between the top and bottom substrates where fretting fatigue is present. As an example, Fig. 8a shows a case regarding a transverse joint tested at  $R=0.1$  and high applied maximum load, while Fig. 8b the transverse section of an analogous case for a longitudinal joint. This type of non-propagating cracks were also observed in specimens failed for shear rupture (Fig. 6c) of the indentation point.

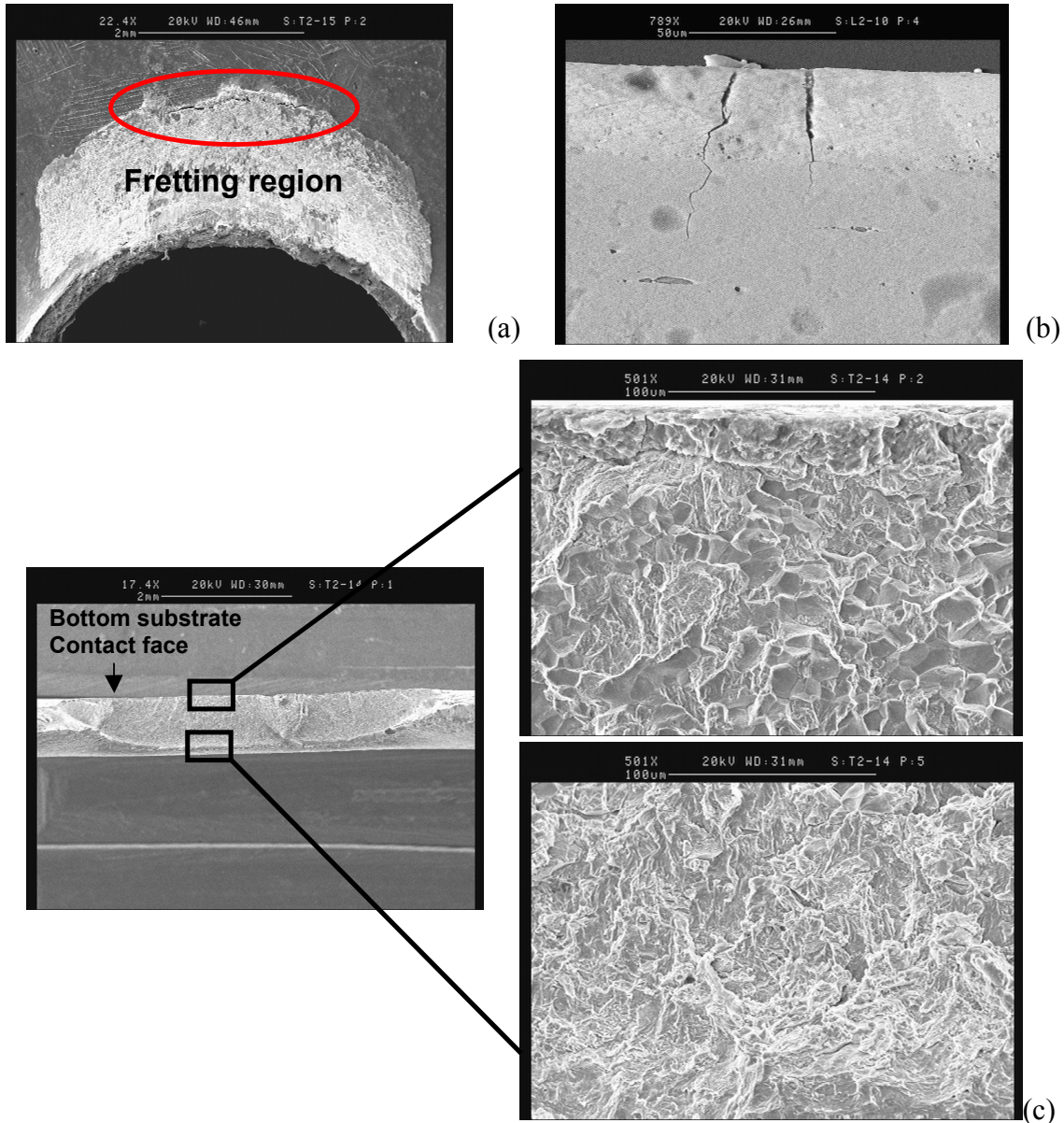


FIGURE 8. SEM observations on failed specimens: a) crack in the contact region of a transverse joint; b) section of a crack in the contact region of a longitudinal joint; c) analysis of the crack surface of a transverse joint.

Eventually, all the specimens failed for crack propagation in the bottom substrate were manually broken and crack surfaces were investigated. Fig. 8c shows an example regarding a transverse joint subjected to  $R=0.1$  and high maximum applied load. It's possible to note that near the contact region a mixed microscopic mode of failure, formed by propagation striations plus fragile failure, is present. The presence of fragile failure in the nucleation region suggests that, at this stage, the material sees a three dimensional stress state. This stress state then vanishes with crack propagation toward the other side of the sheet, where a ductile failure mode is present, even if no typical dimples could be observed. It's important to add that all the observed specimens, independently on joint configuration, stress ratio and maximum applied load, showed the same morphology of crack surfaces just described.

## FEM analyses

FEM analyses were carried out in order to investigate the stress distribution in the sheets composing the joints. Both the joint configurations were modelled by means of thick shell elements with 8 nodes, while truss elements were adopted to model the shape contact between the indentation points (Fig. 9a and b). Dummy plates were included at the ends of the sheets, too.

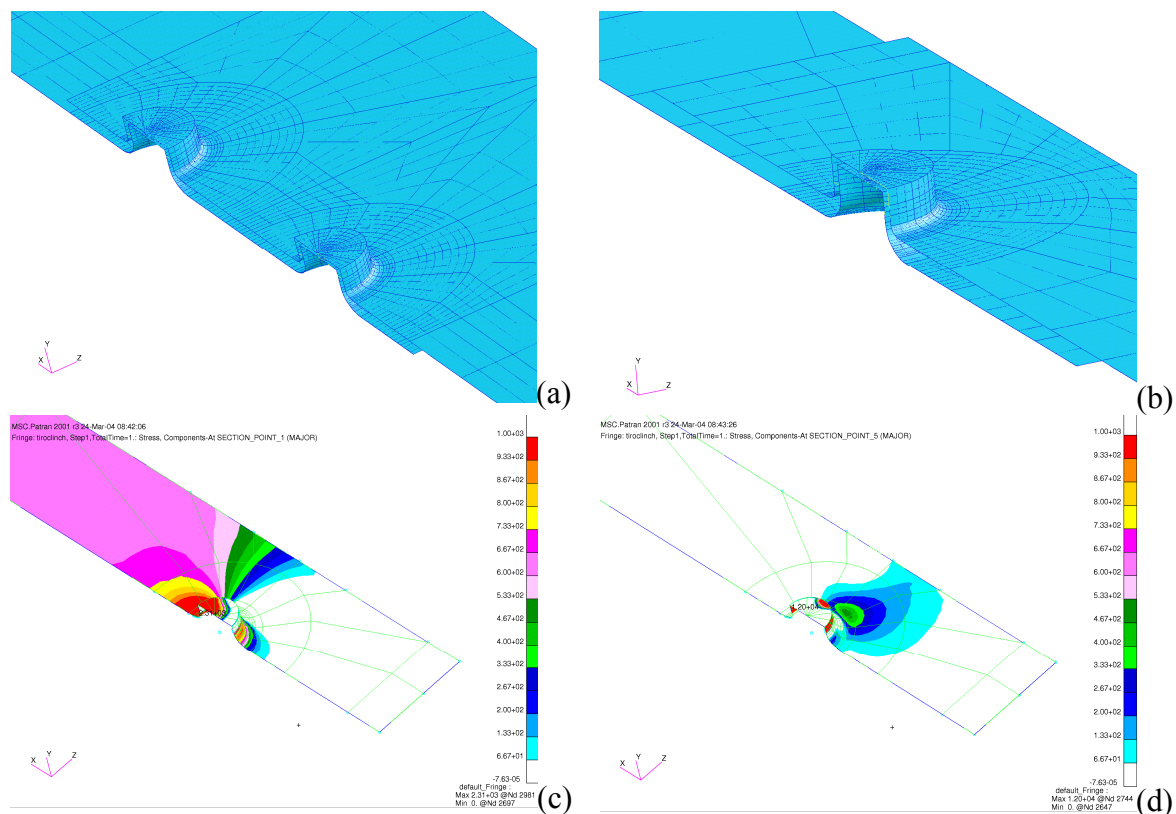


FIGURE 9. FEM models of clinched joints: a) and b) longitudinal and transverse joints; c) and d) maximum principal stress for the internal shell layer (contact region) and the external one (external face) of the bottom substrate.

The applied load was equal to the previously determined ultimate tensile strength. Considering the transverse joint, the most critical point, in terms of maximum principal

stress, was found in the shell layer (section point) corresponding to the internal face of the bottom substrate (Fig. 9c). This layer represents the region where contact is present and is the same where short surface cracks were observed by SEM, as described in the preceding paragraph. It's also interesting to check the trend of the maximum principal stress for the external layer of the bottom substrate (Fig. 9d), that is the one relative to the external face. In this case, stresses are low in magnitude and near to zero denoting the non-criticality of this region and the presence of secondary out of plane bending with shape, in the sheet thickness, without compressive contributions. In the case of the longitudinal joint, the same conclusions can be made at the indentation point nearer to load application, that is where the failures were observed during the tests. Furthermore, the analysis of the hydrostatic stress at the internal shell layer has shown for both the configurations the presence of a three dimensional stress state, as seen in SEM observations.

### **Concluding remarks**

In the present work, fatigue behaviour of clinched joint has been analysed. It has been found that the influence of joint configuration is not significant. More critical is the influence of stress ratio that in fatigue tests can change completely the failure mode. From the point of view of design, the fatigue limit has been found to be 50% of ultimate strength: a value significantly higher than the one of spot welding. SEM observations have shown that the microscopic failure modes can be ascribed to fretting fatigue on parts in contact (crack nucleation) and to secondary out of plane bending effects (crack propagation). FEM analyses supported the second phenomenon showing great stress concentrations in the critical region where all the failures (for low applied stress ratios) were observed.

### **References**

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