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ULTIMATE AXIAL LOAD CAPACITY OF V-BAND CLAMP JOINTS

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ABSTRACT

Band clamps with a flat bottomed V-section are used to connect a pair of circular flanges to provide a joint with significant axial strength. Despite the wide application of V-band clamps, their behaviour is not fully understood and the ultimate axial strength is currently only available from physical testing. This physical testing has indicated that the ultimate strength is determined by two different types of structural deformation, an elastic deformation mode and a plastic deformation mode. Initial finite element analysis work has demonstrated that analysis of this class of problem is not straightforward. This paper discusses the difficulties encountered when simulating this type of component interaction where contact is highly localised and contact pressures are high and therefore presents a finite element model to predict the ultimate axial load capacity of V-band clamps.

Keywords V-band retainer, plasticity, finite element analysis, cold roll forming

1 INTRODUCTION

V-section band clamps are used in a wide range of applications in the aerospace and automotive industries. As stated by Shoghi (2003) they were invented during the Second World War by the Marmon Corporation and are nowadays used to connect together the housings of diesel engine turbochargers and as stated by NASA (2000) to assemble satellites to their launching device. The process of assembling V-band clamps to a pair of circular flanges has recently been investigated using classical analysis by Shoghi et al. (2004), finite element analysis by Shoghi et al. (2003) and experimental validations by Shoghi et al. (2006).

Figure 1 shows a V-band clamp assembled to a pair of flanges in an experimental test rig. These band clamps are assembled by placing them loosely around the flanges, and then tightening the T-bolt nut. The band will then lessen its diameter and apply a radial load. Due to the V-shape of the section and the wedging action this radial load then generates an axial load, pressing both flanges together. Despite their wide application, once assembled to a pair of flanges little is known about the interaction between flange and band. Moreover the failure mode of V-band clamps when undergoing an axial load is not fully understood. Work has therefore been initiated to generate a finite element model able to predict the ultimate axial load capacity and deformation of V-band clamps.

2 PREDICTION OF THE ULTIMATE AXIAL LOAD CAPACITY

Theses band clamps are made of AISI 304 austenitic stainless steel quarter hard with a Young’s Modulus of 227GPa, a Poisson’s ratio of 0.29, a yield strength (0.2% offset) of 648MPa and an ultimate tensile strength of 857MPa, as mentioned in Shoghi (2003). In the FE analyses the material was assumed to be elastic-plastic with linear hardening, as described by Dixit and Dixit (2008). ABAQUS requires all material properties to be added as true stress and strain values so equations (1), (2) and (3) were used to convert the engineering values of the Yield point and the Ultimate tensile strength into true values, as demonstrated by Meyers and Chawla (1999) and Teherani et al. (2006).

In these equations σ_e and ε_e represent the engineering stress and strain values and σ_t and ε_t represent the true stress and strain values.

$$\sigma_t = \sigma_e (1+\varepsilon_e) \qquad (1)$$

$$\varepsilon_t = \ln(1+\varepsilon_e) \qquad (2)$$

$$\varepsilon_{pl} = \varepsilon_t - \varepsilon_{el} \qquad (3)$$

For the finite element models described in this paper, the flange was assumed to be a rigid non deforming body, so it did not need to be meshed, and the band clamp was modelled using a solid body, for which a mesh was required. Assembling of the V-band clamp to the flanges, which in reality is done by tightening the T-bolt nut, was simulated by generating a thermal contradiction so the band clamp was shrunk onto the flanges by applying a reduction in temperature. The initial axial load generated by this procedure was set to 6 kN for all analyses. Failure of the band clamp was then simulated in ABAQUS by moving the flange in the axial direction. At the reference point RP shown in Figure 2, the resistance force of the band clamp acting against the movement of the flange was reported. The highest value of this resistance force represents the ultimate axial load (UALC). As the set up of this V-band joint simulation is a purely symmetrical problem, only one half of the clamp joint was modelled using a 2 dimensional axisymmetric model, in which only one flange was used, along with half a side of the band clamp section. For this half modelled band a boundary condition (BC) was applied to its symmetry plane, so any movement of the clamp in the axial direction was prevented, see Figure 2.

Using the commercial finite element program ABAQUS, initial numerical contact analyses have shown that the problem associated with these analyses is the flange sliding over the V-band clamp, as observed by Barrans and Muller (2009). In real application the contact radius R is usually up to 0.8mm when clamping together housings for turbocharger, whereas for the finite element work presented in this paper the contact radius R was chosen to be 0.5mm, as this is a radius which is a good average for all radii used. The flange angle γ was set to be 20° to match the angle of the V-section, along with the flange thickness t_f to be 4.5mm as suggested by Brown (2009).

Initial finite element analyses by Barrans and Muller (2009) have shown that the ultimate axial load capacity (UALC) highly depended on the diameter of the V-band clamp. As Figure 3 shows, assuming no friction at the contact area between the flanges and the band clamp, the UALC increases for small diameters up to 250mm and then starts to decrease again. It should be noted at this point that for the range of diameters shown in Figure 3 the cross section of the V-band clamp remains unchanged.

This behaviour has further been investigated in more detail by analysing the elastic-plastic failure mode of the clamp. Figure 4 shows that for smaller diameters e.g. 55mm the V-band deforms highly plastically with the V-section being bent so its behaviour was as that of a cantilever, whereas band clamps with large diameters e.g. 1500mm tend to deform only elastically and the V-section does not change its shape, but it deforms in the radial direction. This behaviour for large diameters is due to the cross section area being the same as for smaller diameters but more material exists in the circumferential. This problem is not straightforward as the failure mode is made of a mixture of the change from plastic-elastic deformation to purely elastically, and the deformation by bending the V-section or deforming strictly in the radial and circumferential direction without bending of the V-section. This is therefore important as the axial load must exceed the yield strength to deform a band clamp with a small diameter so it deforms mainly plastic and partially elastic. For larger diameters the axial load leading to failure of the joint can be below the yield strength so less force is needed to fail a joint than for smaller diameters.

Moreover these finite element predictions showed a high concentration of plastic strain on the inside of the flat section, next to the inner radius, as can be seen in Figure 5. This is obviously due to bending of the V-section as it happens for smaller band clamps. Keeping in mind that these analyses were purely static applying a single large force, this concentration occurred immediately after applying the load. In real turbocharger application it is very likely that over a long period of time smaller loads may occur regularly, which lead to smaller strain and stress concentrations. After such a dynamic loading even smaller stress and strain concentration can get higher values after a certain amount of time. Such a concentration could lessen the thickness of the flat section of the band. As it is well understood in literature and is frequently demonstrated at easy tensile tests, this lessen can lead to failure of a material by lessening the thickness even more and reducing the strength of the band clamp or it could even lead to small micro-cracks, which, lead to crack growth.

3 EXPERIMENTAL RESULTS

Experimental tests have been carried out in order to validate the finite element work. V-band clamps have therefore been assembled to a circular pair of flanges which were mounted in an Instron tensile test machine. The experiments were carried out in the same way as the numerical work. After assembling the band camps to the flanges, the flanges were then separated until the band clamp flipped over the flanges and hence failure of the whole joint occurred. The axial load created because of this separation was reported and the peak value of this force was shown to be the ultimate axial load capacity (UALC). All experiments were carried out with V-band clamps with a diameter of 114 mm.

Figure 6 shows the UALC for a series of eight tests that were carried out. The values lie all in a range from 68 kN to 81 kN, which gives an average of 75.5 kN. Comparing these to the numerical value ca.68 kN shown in Figure 2, it can be seen that the experimental values are slightly higher because the contact area in finite element model was assumed to be frictionless whereas in the experiments a certain amount of friction always exists, even after lubricants were applied.

The crack theory with the concentration of plastic strain in Figure 5 can be proven to be correct as well. After investigating V-band clamps used at a diesel engine turbocharger in real application which failed because of a turbocharger burst, the band clamp in Figure 7 clearly shows a crack in the region as predicted before by the finite element model.

4 CONCLUSION

In this paper a finite element model able to predict UALC of V-band clamp joints has been developed and the problems associated with this type of analyses have been investigated.
It was shown that the ultimate axial load capacity highly depends on the flange/V-band diameter, because of the complex plastic-elastic failure mode. The numerical and experimental values for the UALC correlated very well.
The finite element prediction showed high concentrations of plastic strain at the edge of the flat section. It was shown that a crack occurred at V-band clamps mounted to turbochargers for diesel engines as the joint failed. This crack occurred in the flat section in the same region as the finite element model prediction high strain concentrations.

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Figure 1: V-band clamp assembled to a circular pair of test flanges, taken from Barrans and Muller (2009)

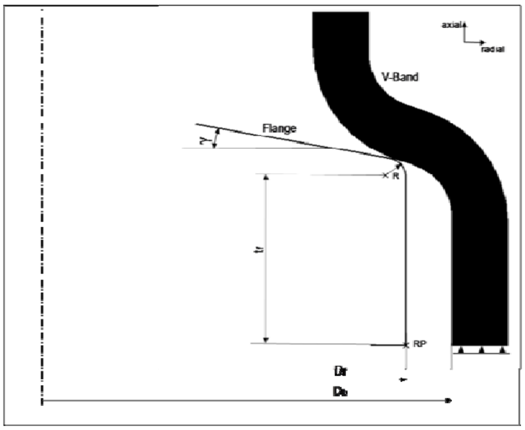

Figure2: Axisymmetric finite element model showing all geometrical parameters, taken from Barrans and Muller (2009)

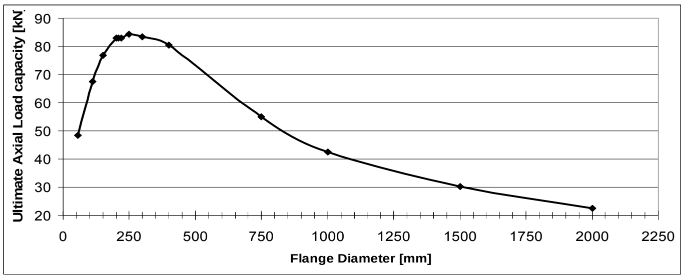

Figure 3: Predicted dependency of UALC on flange diameter, taken from Barrans and Muller (2009)

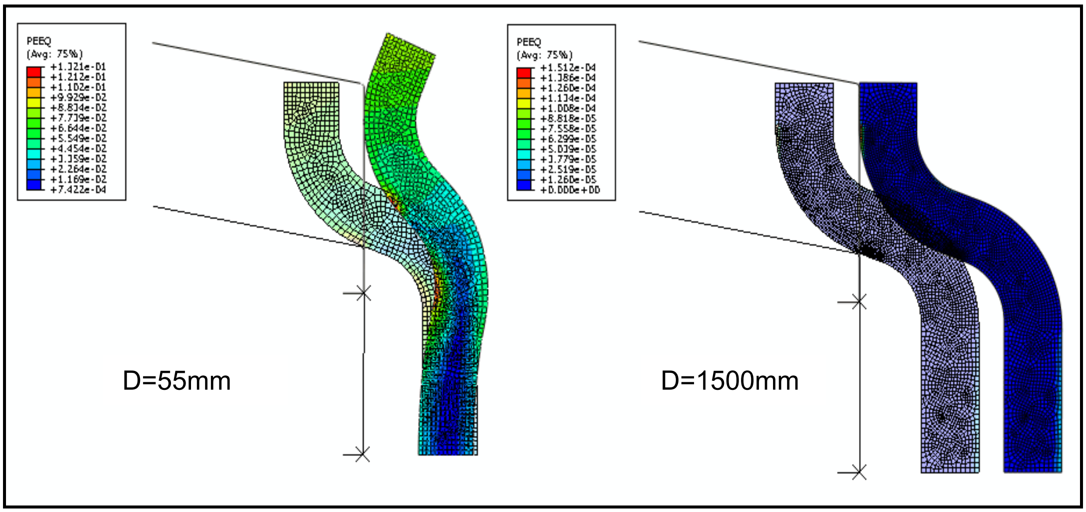

Figure 4: Failure mode of V-band clamps for small and large flange diameters

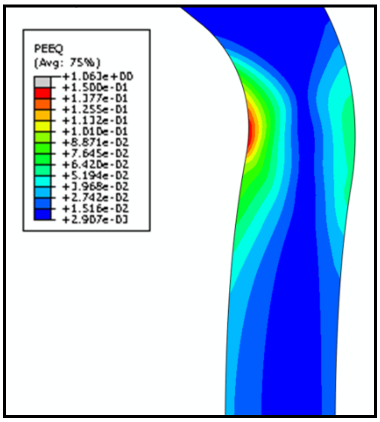

Figure 5: High plastic strain concentration at flat section of V-band clamp

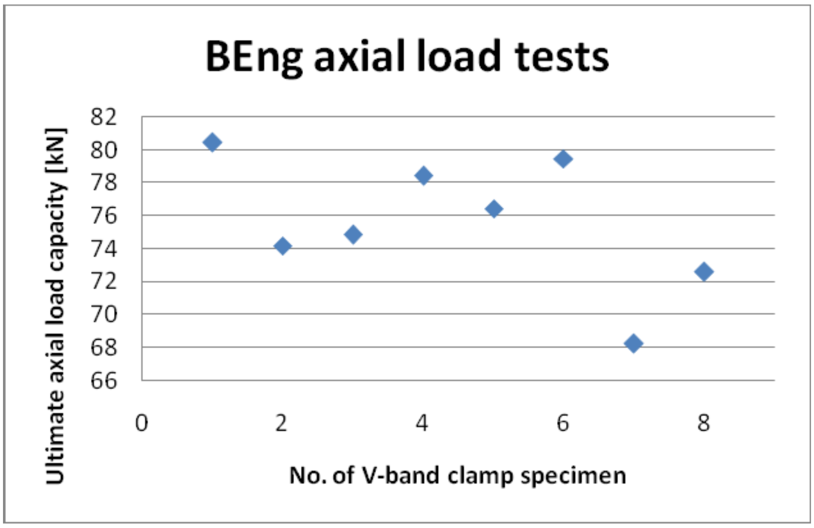

Figure 6: Experimental values for series of axial load tests

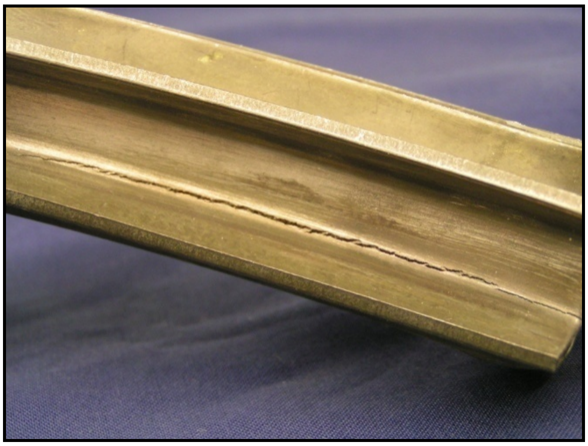

Figure 7: Failed V-band clamp that was assembled to turbocharger for a diesel engine