Study of an interference fit fastener assembly

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Abstract: This paper presents the study of an assembly of two plates using an interference fit fastener. Such an assembly is commonly exploited in aeronautics applications. The interference between the screw and the plates induces a loss of load all along the screw axis due to the combined effect of radial pressure and friction. This effect is simulated using a finite element analysis with Abaqus. The evolution of pressure all along the interference area shows that edges effects appear not only at the external edges but also at the interface between plates. In order to evaluate the capability of sensors to be experimentally exploited, the evolution of the axial strain all along the screw axis is also investigated. This study highlights the influence of the radial pressure on the axial strain on the axis of the screw. The influence of both the interference level and the friction factor are also investigated.

Key words: interference fit fastener, FE Analysis, Abaqus.

1- Introduction

Bolt assemblies are hugely exploited in industry. When the bolt assembly is located in a critical sector, it can be replaced by an interference fit fastener. In that case, the screw contains a cylindrical part that is fitted in a hole that has a lower diameter value. Both parts are locked together not only by the tightening load but also by a radial pressure due to interference in size at their interface diameter. It has been proved that such a process tends to the retardation of cracks emanating from fastener holes [PS1]. For that reason, interference fit fasteners are commonly exploited in space and aeronautics applications. Unfortunately, in some cases, particularly when the interference level and the friction factor are too high, the tightening load can be lost at the interference diameter and a gap can exist between the screw head and the plate. Of course such a state is forbidden in an industrial application. In order to correctly exploit and design such an assembly, it would be interesting to study the axial loss of load along the screw.

Duprat et al. [DC1] have studied the fatigue life prediction of interference fit fastener. They show that in 90% of cases, crack initiation does not take place at the edge of the hole but rather between the bore and the edge of the test specimen. Their results have been compared to a simplified two dimensional finite element simulation. Such a simulation doesn’t enable to study the load transfer between the screw and the two plates that are assembled. More recently, Li and all [LB1] have studied the behaviour of an interference fit fastener with a single aluminium sheet. A photoelastic coating was bonded on the external surfaces of the bolt in order to estimate the strain. The values have been compared to a three dimensional finite element simulation. In order to obtain accurate results, the entire introducing process has precisely been simulated.

In order to obtain more details, studies performed on interference fit and on bolt joint separately are also of interest.

Fontaine et al [FS1,FS2,YC1,YC2] have studied the influence of a form defect on the shrinkage fit characteristics. They show that radial pressure always presents peaks at each contact edges. This tends to induce a non constant loss of load along the screw axis. The edge effect has been precisely studied by testing the influence of various fit forms [OT1]. The average pressure at the shrink-fit interface is commonly calculated by exploiting the Lame’s equation [BT1, PE1]. However, it has also been shown that an analytical study exploiting Lame’s equation can significantly differs from a finite element simulation [ZC1]. It will thus be interesting to analyse the difference between analytical and FE results.

Finite elements studies of bolt assemblies have often been performed. The coupling of bolt assemblies with others mechanical components has been studied [BD1,ZD1] by exploiting three dimensional FE simulations. Local studies can also be performed using 2D axisymetric FE simulations [DC2] and give accurate results. Experimental results are often obtained by placing strain gauges on the cylindrical part of the screw or by exploiting sensors in a hole on the
axis of the screw [DC2,FS3]. The aim of this paper is to investigate the behaviour of an assembly of two plates using an interference fit fastener. Thus, this paper first presents the initial finite element analysis. It details the exploited FE model. Then it shows the evolution of radial pressure and axial strain all along the screw axis. The difference between the FE study and the usual analytical study is explained by exploiting a simplified FE model which includes superposition of elementary loads. The third part of the paper presents the study of the influence of both radial pressure and friction on the axial strain on the axis of the screw. This work is performed in collaboration with industry, for that reason, geometrical data and results are not precisely detailed.

2- Initial FE Analysis

2.1 – The design of the screw

The exploited design is related to the one exploited in aeronautics industry. The screw, composed of a titanium alloy, enables to assemble two plates made of aluminium alloy.

Figure 1: Screw design.

The screw described on figure 1 can be divided in four parts. From left to right we can see, the head, the shank diameter D to be fit in the holes, the thread diameter TD that receives the nut to apply the tightening load and finally the last part that enables the screw to be pulled through the plates.

In order to have a precise and very low friction factor, a coating is applied on the shank diameter.

The operating process is composed of several steps. The screw is first pulled through the plates by a dedicated tool that clenches the screw and applies a given introducing load. Then the load is relaxed, the tool is removed and the screw is broken near the beginning of the thread. Then the nut is exploited to give the tightening load.

2.1 – The FE model

The Finite Element study has been developed using Abaqus. As both the introducing and tightening phases are considered, we can exploit an axisymmetric simulation. The Finite Element model is composed of three parts, the screw, the upper plate and the lower plate.

The meshing is refined near the contact zones in order to obtain more accurate results. The experimental process that is expected to measure the axial strain in the screw axis exploits a hole (fulfilled with an epoxy structural adhesive) in the screw axis. This hole can have a non negligible influence on the global behaviour. Thus, it is included in the FE model.

The boundary conditions on the lower plate enable to simulate the contact with the nut and with the tool dedicated to the introducing step. As the screw is pulled through the plates, the introducing phase is simulated by managing the displacement and the load at the bottom of the screw. The tightening step is simulated by tangential loading on the thread part of the screw.

The contact pressure under the screw head enables to evaluate the load at the upper position. The load between plates can be evaluated by exploiting the contact pressure between plates.

2.2 – Von Mises Stress

The applied tightening load is about half the elastic limit of the titanium alloy. Figure 2 presents the Von Mises stress along the assembly. We can see the load transfer between the screw and the plates.

2.3 – Radial pressure

Considering the previous works related to shrink fit assemblies [FS1,FS2,YC1,YC2,OT1], the radial pressure between the screw and the plates should be constant with only two gradients at the top and bottom edges. The pressure evolution is presented on figure 3. The expected gradients appear but it can also be seen that a discontinuity of pressure appears in the middle axial position where the contact changes from one plate to the other. This was not highlighted by previous works that focused on a unique plate assembly. It could be interesting to investigate further to see whether this phenomenon has a mechanical explanation or is only due to a numerical effect.

Using the Lame equations [BT1,PE1], the average radial pressure for the initial state can be estimated. In our case, it should be about 310MPa. This should induce a loss of 20% axial load under the screw head. The average pressure
obtained by FE analysis is only equal to 280MPa. This loss of pressure is mainly due to the effect of the axial tension of the screw that decreases the radial interference.

The lost of axial load due to the friction factor between the screw and the plates can also be extracted from the FE study from the contact pressures. It is about 7.4% at the interface of the two plates and about 18.3% under the screw head. Thus, the analytical study that does not consider the axial tension overestimates the loss of axial tension.

2.4 – Axial strain

The axial strain is the data that could be experimentally measured. It is presented on Figure 4.

We can see that the axial strain is non constant over a screw section. Moreover, it varies significantly near the screw head and near the nut.

To have more details, the axial strain on the screw axis is presented on figure 5. It is compared to the analytical curve that is defined by considering a uniform tension in each screw section and a uniform loss of tension along the screw axis. Such an analytical model doesn’t consider the axial load transfer in the head section where the axial load in the cylindrical part goes through the external part of the head. The analytical model can’t consider either the load transfer from the thread part of the screw. Thus, the initial and final gradients in the FE curve can’t be taken into account.

Anyway, the obtained FE axial strain is significantly different from the analytical one all along the axis. The FE curve is clearly greater than the analytical curve on the middle part of the screw axis (axial position from 0.3 to 0.8) where the load transfer effects shouldn’t have any influence. In that case, it appears that the axial strain caused by the radial pressure cannot be neglected. To highlight this phenomenon, we propose to build a simplified FE model that only considers the screw. This screw is loaded by three separated loads presented on Figure 6. A tangential pressure on the thread simulates the axial tightening load, a tangential pressure on the external radius simulates the loss of load at contact and a radial pressure simulates the interference pressure. Boundary conditions are added to take into account the contact under the screw head.

The results are compared with both the full FE study and the analytical model. The axial strain curves are presented on...
3- Advanced FE Analysis

The loss of load on the screw is mainly due to the interference level and to the friction factor. It is thus now clear that the interference level directly influences the axial strain on the screw axis. For that reason we have decided to study the influence of both the friction factor and the interference on the loss of load and on the axial strain.

Previous experimental tests have enabled to evaluate a lower and an upper value for the friction factor. In order to evaluate the bounds for interference, we have considered that the hole in the plates can be well measured whereas we can’t precisely measure the external diameter of the cylindrical part of the screw because of the coating. Thus, the bounds for the interference are determined with the tolerance on the screw diameter.

3.1 – Influence on the loads

The obtained values for the loss of axial load are presented on table 1.

<table>
<thead>
<tr>
<th></th>
<th>Load lost under screw head</th>
<th>Load lost between plates</th>
</tr>
</thead>
<tbody>
<tr>
<td>reference</td>
<td>18,3%</td>
<td>7,4%</td>
</tr>
<tr>
<td>lower friction</td>
<td>15,8%</td>
<td>6,1%</td>
</tr>
<tr>
<td>lower interference</td>
<td>15,4%</td>
<td>5,9%</td>
</tr>
<tr>
<td>higher friction</td>
<td>20,8%</td>
<td>8,7%</td>
</tr>
<tr>
<td>higher interference</td>
<td>21,2%</td>
<td>8,8%</td>
</tr>
</tbody>
</table>

Table 1: Loss of axial load.

Firstly, it appears that considering the exploited bounds on the friction factor and on the interference level, the load lost under the screw head and between plates do not significantly change. Nevertheless these variations could be highlighted experimentally.

Secondly, it appears that both the lower friction value and the lower interference value have the same influence on both loss of load. The load lost under the screw head and between plates is also very similar for the higher interference level and the higher friction factor. We can thus conclude that the variations on the friction factor and on the interference have a similar influence on the loss of loads.

3.2 – Influence on the axial strain

The evolution of the axial strain on the axis of the screw is presented on figure 8.

It appears that the interference level has a greater influence than the friction factor. The potential variation on the friction factor has almost no influence on the axial strain. This enables the interference level being evaluated by exploiting the axial strain curve.

4- Conclusion

An axisymmetric Finite Element model has been exploited to analyse the behaviour of an interference fit fastener. The analysis of the tightening phase enables to highlight several points.

We have first analysed the pressure between the shank diameter of the screw and the holes of the plates. As expected, the increase of pressure at the external edges of plates is shown. The loss of pressure that occurs at the inner edges of plates is highlighted for the first time. It thus would be interesting to study this effect in details. We also show that the obtained average pressure is less than the one that could be estimated by an analytical study that would neglect the axial tension. Thus, such an analytical study tends to overestimate the load lost under the screw head and between plates.
We have also studied the axial strain on the axis of the screw in order to evaluate the efficiency of sensors. An original FE model that enables to separate the effects of elementary loads has been exploited. It shows that the radial pressure on the shank diameter of the screw significantly influences the axial strain of the screw.

In order to have more details, a study related to the influence of the interference level and the friction factor has been performed. It shows that both similarly influence the loss of load but also that only the interference level significantly impacts the axial strain curve on the axis of the screw. This is a key issue as it means that an experimental test can evaluate the interference level without being influenced by a potential evolution of the friction factor. Moreover, it also means that such an experimental test will not be able to easily highlight any evolution of the friction factor.

It will thus be interesting to carefully develop experimental test benches and try to extract the evolution of the axial strain in the screw axis.

5- References


