RESIDUAL STRESS ANALYSIS BY CONTOUR METHOD ONTO COLD EXPANDED HOLE ASSEMBLY– COMPARISON WITH FEA

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1 Abstract

Introducing high residual stress in a hole is critical for many fatigue life components, especially in aerospace industry. The process introduces deep residual stress on hole surface providing fatigue life enhancement.
Cold expansion should be controlled to guaranty both the homogeneity and the repeatability of the compressive stresses generated by the process. However, it is difficult to control the stresses generated into the component with usual residual stresses measurement methods.
This is why Meliad and Capaero with Mat-In-Meca developed the contour method allowing to control the deep stress profile generated in the part.
This study shows how experimental measurement by the contour method and numerical model through finite element analysis gives effective characterization of the residual stresses introduced after hole expansion.

Material: 35NCD13 Steel

2 Objectives

This study shows how experimental measurement by the contour method and numerical model through finite element analysis gives effective characterization of the residual stresses introduced after hole expansion.

3 Processes and methods

3.1 Split sleeve cold expansion process

Split-sleeve coldworking was developed in the early 1970’s as a way to improve joint fatigue performance by expanding or compressing the material around the fastener hole. In the split-sleeve process, this is accomplished by inserting a mandrel that has been prefitted with a disposable sleeve, through a fastener hole, and pulling the mandrel back through the sleeve.
The internal surface of the sleeve is pre-lubricated with a special dry lubricant, protecting the mandrel from excessive wear, and reducing the amount of force required to pull the mandrel.

3.2 Split sleeve expansion procedure

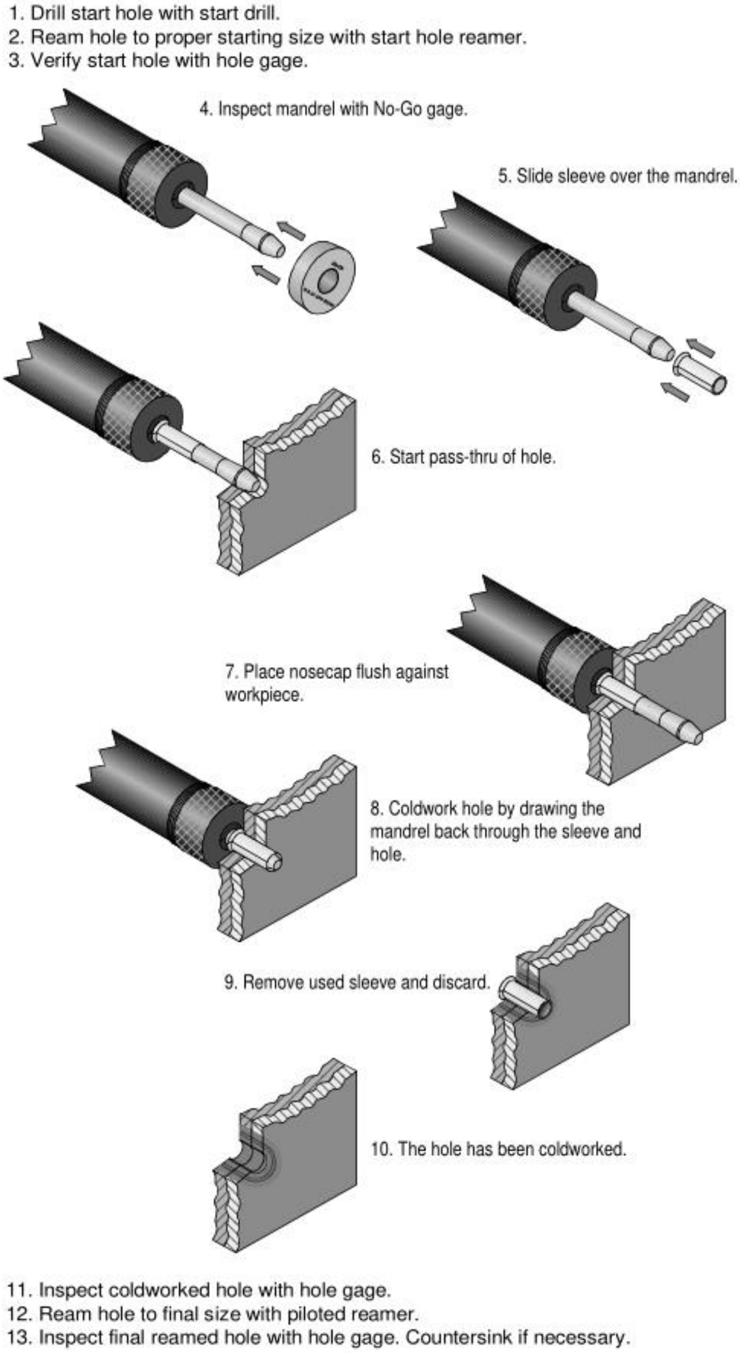


Figure 1 Split sleeve expansion procedure

3.3 Contour method

The contour method is a destructive method to obtain the residual stress map on the section of a part. This method allows a very different approach to stress measurements by giving a complete map and not only a spot value.

The method was firstly introduced in 2000[1] and has seen a strong development in the 2010 decade.

This method determines residual stress by carefully cutting the specimen into 2 pieces and measuring the resulting deformations dur to residual stress redistribution. The displacement measured is used to run a finite element analysis model allowing to obtain the original stress state inside the specimen along the cut plan.

Contour method is widely used on big parts at early manufacturing stages such forging, heat treatment and pre-machining.
The progress made during the last decades on the result uncertainty and the cutting technics allows to work on smaller and more finished part.

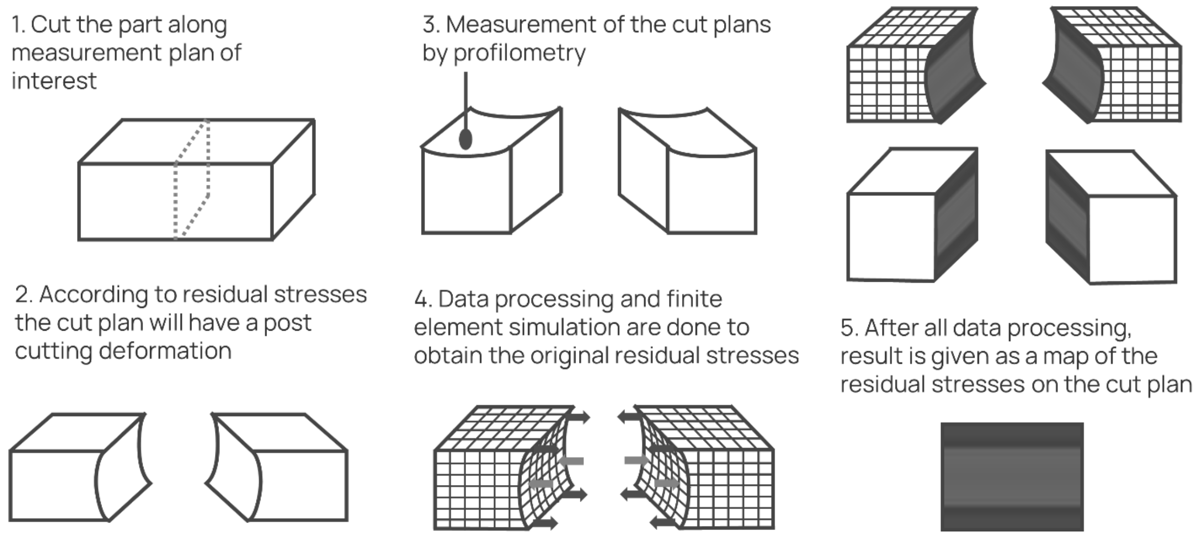


Figure 2 Contour method principle

4 Study

In this study we intended to assess the reliability of contour method on cold expanded hole.
Measurement of residual stresses is particularly difficult on cold expanded holes due to accessibility reasons:

- X-Ray measurement can measure close to the hole but on surface only
- Hole drilling method is usually quite far from hole edge because of the gauge size and can't capture enough residual stresses

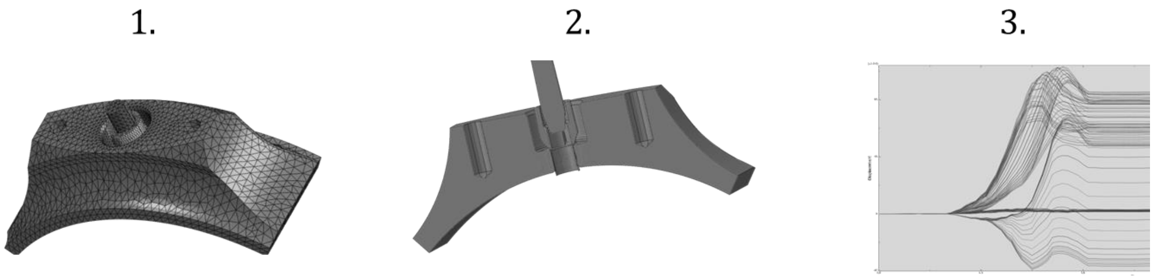
Contour method offers a new opportunity to get residual stresses map around the hole and confirm the residual stresses introduced by the process.
After a finite element analysis to get an evaluation of the residual stress map, a representative sample has been cold expanded before being evaluated with the contour method.
This offers a unique opportunity to compare both methods result.

4.1 Finite element analysis

4.1.1 Method

Capaero simulation was made with Abaqus software using a 3D model including expansion tools (Nosecap, mandrel and split sleeve) with the original part geometry.
Contacts management and meshing parameters are parts of Capaero know-how to obtain reliable results in a limited computing time.
Experience shown that 3D model is more accurate than 2D ones and allows to fully simulate the sleeve deformation as well as the split impact on the residual stresses.
Simulation is done in 3 main steps:

1. Finite element modelling of the structure for the different expansion configurations. A convergence study has been made for each configuration.
2. Numerical simulation of the hole split sleeve and its stabilized state after expansion for all studied configurations.
3. Analysis of the numerical simulations and the impact of the split sleeve



Simulated configurations were based on minimum and maximum expansion ratios created by tooling tolerances.
For this study, only one result is shown: the one corresponding to the sample measured in contour method.
The dynamic explicit simulation was done taking special care of contact properties. This kind of simulation tend to increase the stresses oscillations after spring back but Capaero experience allows to lower the uncertainness of the results.

4.1.2 Results

In this study, the measurement plan was taken at 90 degrees of the split location to avoid local behaviours due to the split.

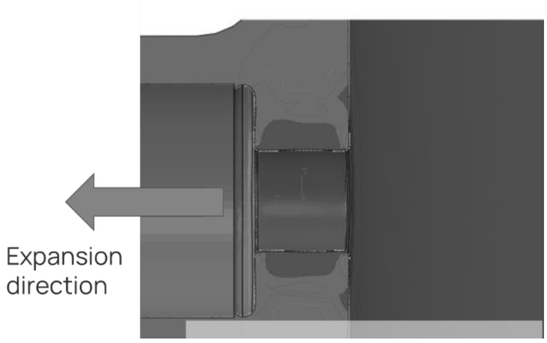


Figure 3 plastic strain map shown in a cut view of the cold expanded hole

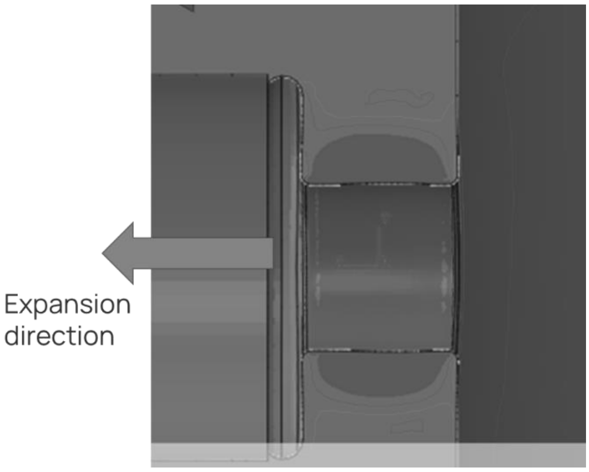


Figure 4 Tangential stresses after expansion

4.2 Residual stresses measurement using contour method

4.2.1 Method

The sample measured has a simplified geometry compared to the original part used for the simulation. However, the local stresses are expected to be similar.

First, the part was cut using and EDM machine and a thin cutting wire to prevent has much has possible effects of the cutting operation on the part.

Then the 2 cut surfaces are measured using a microscope.

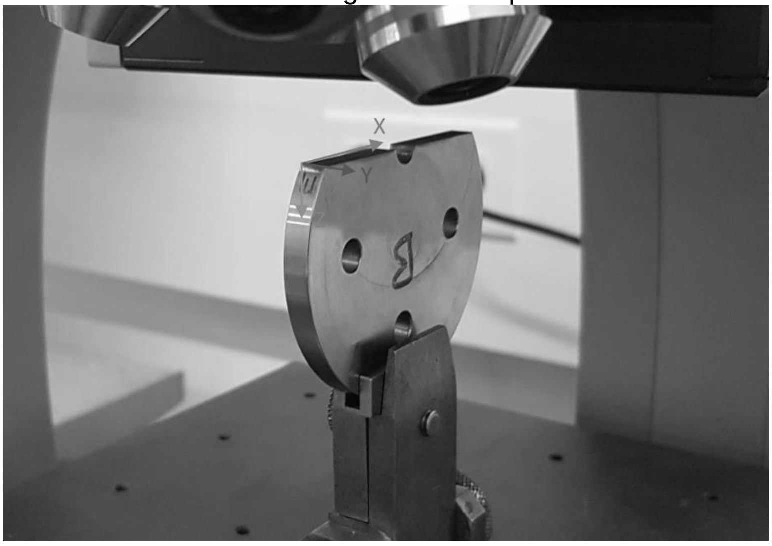


Figure 5 one side of the sample being measured to obtain the surface geometry

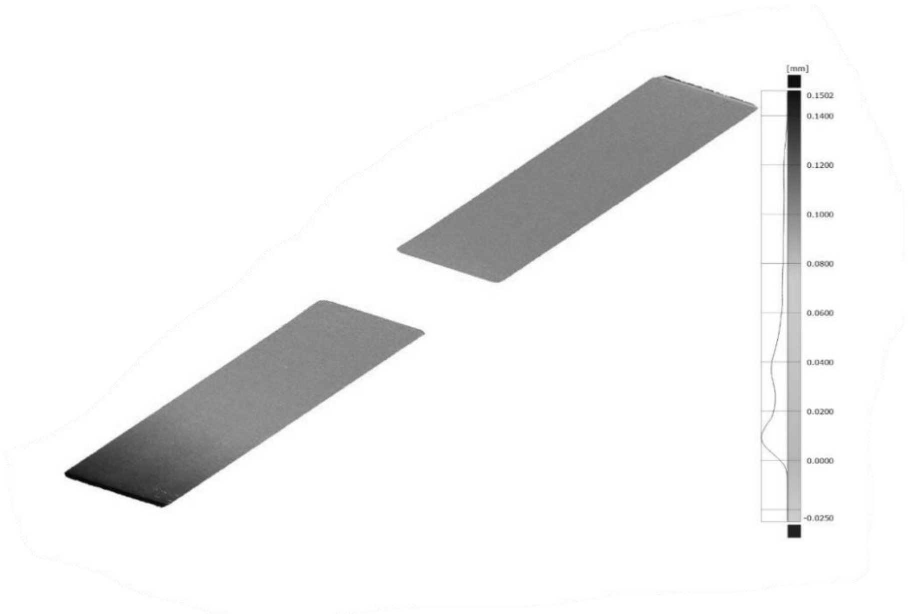


Figure 6 3D measurement result

Both surfaces are the combined to obtain an average surface. Data are filtered using an interpolation parameter aiming to reduce roughness effect and keep only the variations dues to residual stresses relaxation.
At the final step, a final element analysis is performed with deformation data to obtain the original residual stresses state.

4.2.2 Results

Tangential residual stresses measured by the contour method are sown on the following figure:

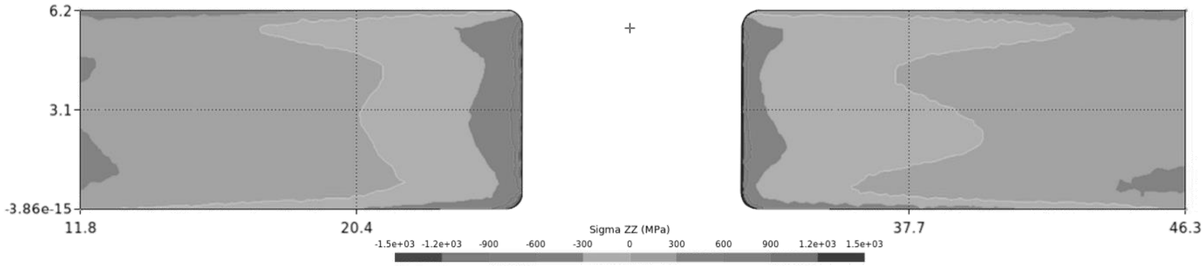
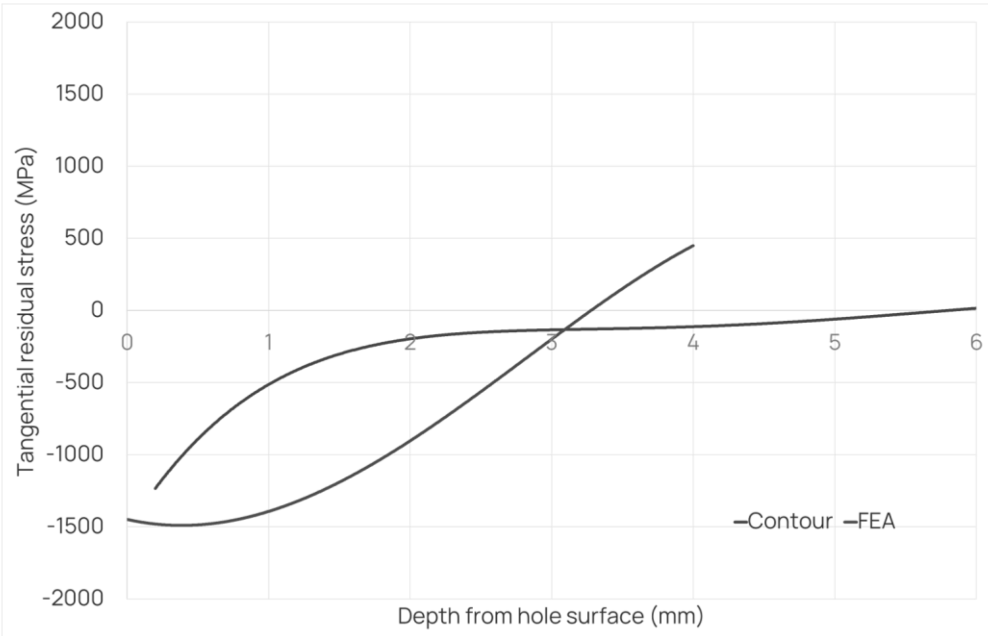


Figure 7 Tangential stresses measured with contour method (MPa)

4.3 Comparison between FEA and measurement

FEA and contour method agree on some points. They show that maximum compressive stress near the surface is higher than 1000 MPa and depth-to-zero is between 3 and 5 mm.
Significant differences are also clearly visible. FEA shows a stress plateau while contour method describes immediate decrease.
Uncertainty for the contour method is in the order of ±10%. It is also known that the contour method is hardly capable to measure very high gradient (1000 MPa/mm) close to surfaces.
FEA results is directly dependent of mechanical properties such as yield strength and work hardening considered for the elasto-plastic model. Now, standard properties have been considered for the present steel grade.
Observed differences will be discussed in further study in the light of reproducibility measurement for the contour method, sensitivity study for the FEA, and additional measurements with XRD at Meliad.



5 Conclusion

Contour method shown interesting results to allow residual stresses analysis on a cold expanded hole. This approach offered data we can't get with other conventional methods.
However, further work is required to improve the exactness of the values obtained and the compression depth obtained by cold expansion.
Working on the dimensional data acquisition close to hole edge could improve the final result.

6 List of references

[1] Prime, MB, Gonzales AR, 2000, *The Contour Method: Simple 2-D Mapping of Residual stresses*, The 6th International Conference on Residual Stresses, IOM Communications, London, UK, Oxford, UK 617-624.