REVIEW

of a dissertation
for the acquisition of the educational and scientific degree "doctor" (PhD)

Field of higher education: 5. Technical sciences
Professional field: 5.1. Mechanical engineering
Doctoral program: Construction Mechanics, Strength of Materials
Author: Eng. Petya Hristoforova Daskalova, MSc
Theme: Increasing the fatigue life of fastener holes in aluminum alloy D 16 AT using a modified split mandrel cold working method
Reviewer: Prof. Eng. Stoyko Atanasov Gyurov, PhD, Institute of Metal Science, equipment, and technologies with Center for Hydro- and Aerodynamics "Acad. Ang. Balevski" at the Bulgarian Academy of Sciences – (IMSETHC-BAS)

1. Topic and relevance of the dissertation

The high-strength aluminum alloy 2024-T3, an analogue of D16AT, is widely used in the aviation industry due to its favorable strength/weight ratio. A number of parts and assemblies such as aircraft skins, panels, frames, beams and other critical structural parts in aircraft construction are assembled using Fastener holes (FH), which are natural stress and strain concentrators. Dynamic stresses during operation cause material fatigue, starting around the surface of the FH. A proven effective approach to increasing the fatigue life of aluminum components with FH is their cold expansion. The most commonly used methods are Split Sleeve Cold Expansion (SSCE) and Split Mandrel Cold Working (SMCW). Both methods require technological cycles containing a large number of control operations combined with a narrow tolerance on the size of the pre-machined FH. To overcome these shortcomings, a new modified variant of the SMCW method, called Modified Split Mandrel Cold Working (MSMCW), has been invented. It provides constant tightness with a relatively wide tolerance on the initial diameter of the hole. As a result, the technological cycle for SMCW is reduced, which significantly reduces the time and overall production costs. However, there is a lack of available literature data to evaluate the effectiveness of MSMCW for modifying the Surface integrity (SI) characteristics around holes in correlation with the pulsating tensile fatigue behavior of 2024-T3 aluminum alloy specimens.

This justifies the formulation by the doctoral student of the following main goal of the dissertation work: *To experimentally evaluate the effectiveness of the*

new Modified Split Mandrel Cold Working (MSMCW) method for improving Surface Integrity (SI) around Cold Expansion of Holes (CEN) and increasing the Fatigue life (FL) of structural elements made of aluminum alloy 2024-T3 under conditions of a relatively large tolerance of the pre-machined holes.

The following main objectives were accomplished to reach the aim:

1) The main approaches and the modern methods/techniques for increasing the FL of structural elements with FH were systematized and analyzed;

2) The parameters of the tool and device for MSMCW implementation were evaluated;

3) The SI characteristics of the material around the Cold Expanded Holes (CEH) were investigated in terms of the distribution of Residual Stresses (RSs), microhardness and microstructure in bush-type workpiece subjected to cold expansion using MSMCW under conditions of a relatively large tolerance of the pre-drilled holes;

4) A comparative experimental study of the fatigue behavior of flat fatigue workpiece with FH, from aluminum alloy 2024-T3 subjected to cold expansion using MSMCW under conditions of a relatively large tolerance of the pre-drilled holes was conducted.

The topic is current and debatable, and the tasks are in a logical sequence, appropriately selected, and solving them guarantees achieving the set goal.

2. Review of the cited literature

The literature includes 128 titles – articles, reports, books and websites. All sources are in Latin, covering the period from 1841 to 2022. The cited sources cover all aspects of the issue under consideration, are accompanied by in-depth comments, which has allowed the doctoral student to draw conclusions and generalizations, accurately formulate the problem and correctly determine the goal and objectives of the dissertation work. This gives me reason to claim that the doctoral student has extensive knowledge of the topic of the dissertation and is thoroughly familiar with the current state of the problem.

3. Research methodology

The methodology is based on an experimental-analytical approach. It is logically structured, scientifically justified and provides an adequate basis for achieving the goal and answering the tasks set in the dissertation.

1) The test specimens are correctly selected and are made for:

• Determining the distribution of circular residual stresses (RSs), the microstructure and the microhardness profile of the material around the holes. They are bushings with nominal dimensions: outer diameter $D = 32\ mm$ and

height (thickness) $\delta = 6\ mm$. Their axisymmetric geometry guarantees correct experimental results;

• One-dimensional tension - flat;

• Fatigue tests - flat.

2) The following analytical methods were used:

• X-ray diffraction analysis for measuring residual stresses;

• Optical and electron microscopy;

• Measurement of microhardness;

• Study of fatigue behavior.

The dissertation is structured in four chapters.

Chapter 1 examines the current state of the problem of increasing the fatigue life of structural elements with FH. The following are analyzed: the role of FH in industry; the phenomenon of material fatigue and material fatigue around the FH; modern methods for increasing the fatigue life of structural elements with FH are considered; methods for Surface Cold Working (SCW); methods for introducing of beneficial compressive hoop RSs; methods for introducing of beneficial compressive hoop RSs and improving SI. The chapter ends with conclusions on the basis of which the goal and tasks are defined.

Chapter 2 discusses a modified method for cold expansion of FH. An analysis of the basic SMCW method and the modified Split Mandrel Cold Working (MSMCW) method is carried out. The stages of the technological cycle are considered and geometric calculations are performed. A tool and device implementing the MSMCW method are developed.

Chapter 3 examines the effectiveness of the MSMCW method for improving Surface Integrity in 2024-T3 aluminum alloy sleeve specimens. The experimental results obtained for the SI characteristics prove that the application of MSMCW under the conditions of the usual engineering practice tolerances of the machined hole diameters will significantly reduce the dispersion of the SI characteristics around the holes and hence significantly improve the fatigue behavior.

Chapter 4 examines the effectiveness of the MSMCW method for increasing the FL of sheet structural elements with FH of aluminum alloy 2024-T3 with a view to their application in aircraft construction. Comparative experimental study of the fatigue behavior of a pulsating cycle confirms the effectiveness of the MSMCW method for significantly increasing the FL – more than six times based on fatigue strength at 10^6 cycles compared to the conventional case of hole processing only by cutting.

The obtained $S - N$ (Vöhler) curves confirm the effectiveness of the new MSMCW method in conditions of excessively large dispersion (0.2 mm at a nominal diameter of 8 mm) of the diameters of the pre-drilled holes.

4. Contributions

I accept without significant corrections the contributions proposed by the doctoral student.

A. Scientific and applied contributions

1. Morphological classification scheme of the main approaches and the methods realizing them for increasing the FL of metal structural elements with FH it is proposed;
2. It has been proven that, under conditions of excessively large dispersion of the diameters of the pre-processed holes, the MSMCW method provides an intensive and deep zone with introduced beneficial hoop RSs on both end faces of sleeve-type samples made of 2024-T3 aluminum alloy after CEH and after final reaming of the holes;
3. The effect of grain refinement near the surface of the holes in 2024-T3 aluminum alloy after CEH by the MSMCW method under conditions of different pre-processed hole diameters was established;
4. It was found that the microhardness on the end faces of 2024-T3 aluminum alloy samples subjected to CEH with different initial hole diameters is 25 % higher compared to that in the as received condition;
5. Based on the microhardness profiles in axial sections, the presence of a gradient in the circumferential direction was established, due to the difference in equivalent plastic deformation in axial sections corresponding to the planes of symmetry of the segment and the notch of the tool implementing the MSMCW method;
6. It has been proven that the removal of a plastically deformed layer of appropriate thickness around the CEH during final reaming provides a homogenizing effect in the distribution of the hoop RSs in the axial direction, which improves the fatigue behavior under pulsating cycles of sheet components made of 2024-T3 aluminum alloy;
7. S-N (Wöhler's) fatigue curves of a pulsating cycle were obtained, proving the effectiveness of MSMCW.

B. Applied contributions

8. An economically effective process for CEH, ensuring constant tightness under conditions of excessively large dispersion of the pre-processed hole diameters;

9. A database it is created for the characteristics of SI (RSs, microhardness, microstructure) in sleeve-type samples of 2024-T3 aluminum alloy, subjected to Cold expansion (CE) using the MSMCW method in correlation with the degree of cold expansion DCE and the thickness of the metal layer during final reaming.
10. A database it is created for the FL of the pulsating cycle of flat samples with FH of 2024T3 aluminum alloy, processed only by cutting and by the MSMCW method in correlation with the degree of cold expansion DCE and the thickness of the metal layer during final reaming.

5. Publications and citations of publications on the dissertation

The doctoral student has presented a list of 5 (five) publications on the dissertation. One of which is in a journal referenced and indexed in the world-famous databases Scopus and Web of Science and 4 (four) at international scientific conferences. All works develop problems covering the topic of the dissertation. In one of the works, the doctoral student is in first place, and in two in second place. All publications are co-authored with her scientific supervisors. 7 (seven) citations in articles referenced and indexed in the world-famous databases Scopus and Web of Science have been noted. This gives me reason to claim that the results of the dissertation have been sufficiently popularized.

6. Authorship of the results obtained

There are no separation protocols for the materials of the dissertation, therefore I assume that the doctoral student has a leading role in the development of the dissertation and at least an equal participation in the publications presented.

The doctoral student's scientific supervisors are scientists of international renown, authors of a large number of publications in journals referenced and indexed in Scopus and Web of Science, as well as patents on the issues developed in the dissertation, which is why I exclude plagiarism.

7. Abstract and author's reference

The abstract is of a reasonable volume of 33 (thirty-three) pages and reflects the structure of the dissertation work, the results obtained, the conclusions drawn from the research and the contributions. However, there is no Table of Contents and the pages are not numbered, which makes it difficult to compare with the dissertation. The illustrations (graphs, photos and tables) are of excellent quality and are fully informative.

Information on LAW on the Development of the Academic Staff in Republic Bulgaria and the Regulations of the Technical University of Gabrovo: The number of points on Indicator G Sum from 5 to 11 is 54,6 points, at required 30. The doctoral student fully meets the requirements of LAW on the Development of the

Academic Staff in Republic Bulgaria and the Regulations of the Technical University of Gabrovo for the acquisition of the educational and scientific degree "doctor" (PhD).

8. Opinions, recommendations and remarks on the dissertation

I have no critical remarks regarding the conclusions drawn and the contributions received in the dissertation.

Only recommendation: the dissertation would benefit if the connection between the individual chapters and the publications on the dissertation were indicated, for example, at the end of each chapter it should be indicated in which of the publications the results obtained are presented. The same applies to the contributions.

9. Conclusion

I believe that the presented dissertation meets the requirements of the LAW on the Development of Academic Staff in Republic of Bulgaria and the requirements of the Technical University of Gabrovo for the acquisition of the educational and scientific degree "doctor" (PhD). I propose that Eng. Petya Hristoforova Daskalova, MSc acquire the educational and scientific degree "doctor" (PhD) in the field of higher education - 5 Technical Sciences, professional field - 5.1 Mechanical Engineering, doctoral program - "Construction Mechanics, Strength of Materials".

Signature: ……/signature/……
/Prof. Eng. Stoyko Atanasov Gyurov, PhD/