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INFLUENCE OF RESIDUAL STRESS LEVEL ON FATIGUE LIFE OF ALUMINIUM ALLOY SPECIMEN AND METHODS OF SPECIMEN PREPARATION

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Abstract

Exova Plzeň tests the load control fatigue test according to the required specifications due to the quality control on rolled aluminium sheets and plates.

Although the machining process is described in specifications in a very detail way, the first test results were approximately 10 % lower than expected. Some round robin test results met the requirements while some others did not. At first the program was focused on the final step of sample machining, i.e. polishing. Based on consulting other Exova laboratories, West Bohemian University and some producers for turning tool tips, the range of compression residual stress was determined.

At the beginning of the program it was incorrectly anticipated that the compression residual stress is caused by polishing; late on was proven that it is caused especially by turning. Next steps were focused on the testing of different types of commercially available tool tips and their geometry. These tests didn't bring satisfactory results. It led to the first tests of our tool tip modification. In 2011 we started cooperating with the Hofmeister Ltd. Company, who are capable to machine tool tips by laser technology.

ČVUT FJFI developed a method of residual stress measurement for our round aluminium samples. At least one sample was machined by each modified tool tip and analysed by ČVUT subsequently.

The current results indicate positive progress in reaching the required residual stress level. The repeatability of production and the life time of tool tips are still to be verified.

Keywords: Fatigue, residual stress, tool tip, modification, surface roughness

1. INTRODUCTION

Exova Plzeň started a business relationship with a supplier of rolled aluminium sheets and plates. The load control fatigue test is required by specifications for the quality control. Four blanks are removed from each product, turned and polished in order to produce test specimens. Since 2010 Exova Plzeň has become one of two laboratories in the world able to machine and test this type of samples in the required quality.

2. SPECIFICATION AND REQUIREMENTS

Four blanks are removed from each aerospace aluminium alloys plate. The plates are made from alloys 7050T 7451, 7475T 7351 and 7075T 7351. Thicknesses of these plates are between 38,1 to 240 mm. Machining and test is performed according to specifications BMS, MEP, AMS, etc. The test specimen is simple round sample of 12,7 mm diameter (Fig. 1).

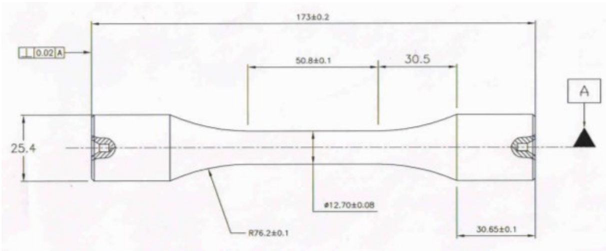

Fig. 1 Test specimen [2]

The specification describes the machining process and requests some steps. The final machining pass must be less 0.015 inch and Ra less 36 µin. The polishing must be longitudinal and min. 50 µm must be removed. This layer must be removed in three steps by 400 and 600 grit paper and crocus cloth [2], [3].

The test must be performed according to ASTM E466. Purpose of the test is material´s quality (casting and rolling issues - porosity, inclusions,..). The test conditions are load control fatigue test, sin waveform, R ratio 0.1, frequency at 20 or 30 Hz, max. stress 35 Ksi and run out 300 000 or 800 000 cycles [2], [3].

The test results show the quality of the material. Two criteria are described for the material. The first is for individual test result, where each specimen must reach min. 90 000 or 350 000 cycles (depends on the specification). The second is for log. average of all four results, where the average must exceed. 120 000 or 760 000 cycles.

3. ROOT CASE ANALYSIS

Although the machining process is described in specifications in a very detail way, the first results were approximately 10 % lower than those of expected. It was caused by the initiation from the specimen surface. The crack initiation should start from internal defects like porosity (material´s quality check). It is expected, that the internal defect will be greater than approximately 50 µm (Fig. 2).

Several round robin tests were performed. Some of them met the requirements while some others did not. The subsequent program for identifying the reason of the premature crack initiation was also based on the round robin testing. At first the program was focused on the final step of sample machining, i.e. polishing. The reason of behaviour was revealed after a few months of testing different types of polishing and consulting other Exova laboratories, West Bohemia University and some producers for turning tool tips.

Based on ur experiences and many round robin tests, we found the problem is connected to in the residual stress level after machining. That is why the cooperation with the Czech Technical University in Prague (ČVUT) FJFI started.

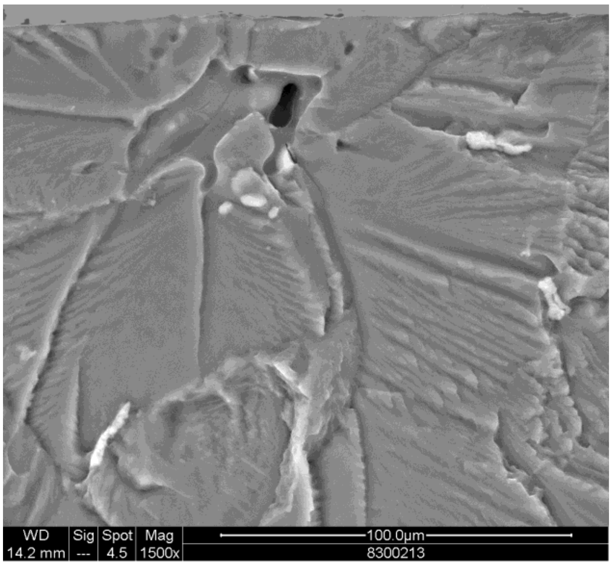

Fig. 2 Internal defect

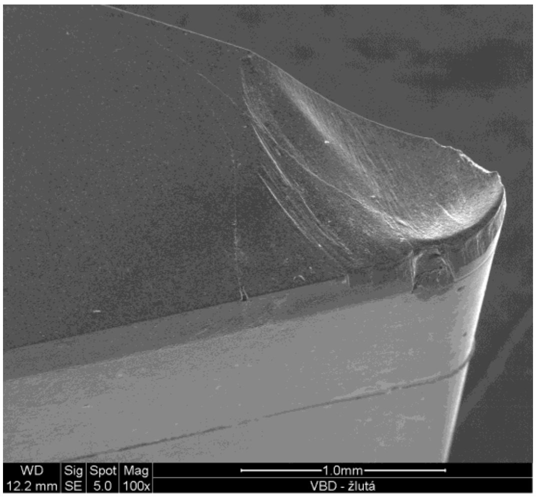

Fig. 3 Modified diamond tool tip

4. APPLIED PROCESS

At the beginning of the program it was incorrectly expected that the compression residual stress is caused by polishing; later on has emerged that it is caused especially by turning. Next steps were focused on the testing of different types of tool tips and their geometry. These tests still did not bring satisfactory results. It led to the first tests of our tool tip modification (Fig. 3). These tests of controlled modification were based on Exova Glendale Heights laboratory experience. The tool tips were modified on Inco 718 at first and later on steel bars as well. In 2011 we started cooperating with Hofmeister Ltd. Company, who are capable to machine diamond tool tips by laser technology with a very high repeatability.

Because the reference material was not available in sufficient quantity, it was very difficult to perform the comparative fatigue test on a reasonable number of samples. That is why the cooperation with the Czech Technical University in Prague (ČVUT) was started. X-ray diffraction analysis was used for the evaluation of macroscopic residual stresses. The evaluation of diffraction patterns was difficult, because of the grain size and rolled structure of material (Fig.4). ČVUT developed a method of residual stress measurement for our round aluminium samples and turn by the specimen during the measurement. At least one sample was machined by each modified tool tip and analysed by ČVUT subsequently.

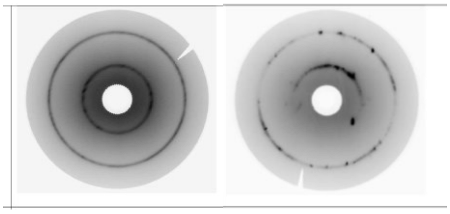

Fig. 4. Diffraction patterns without and with rotation [6]

On Fig. 5 is the description of the process from A to E. It means from worn tool tip to machined tool tip by laser. Both tool tips are always scanned and the shapes compared.

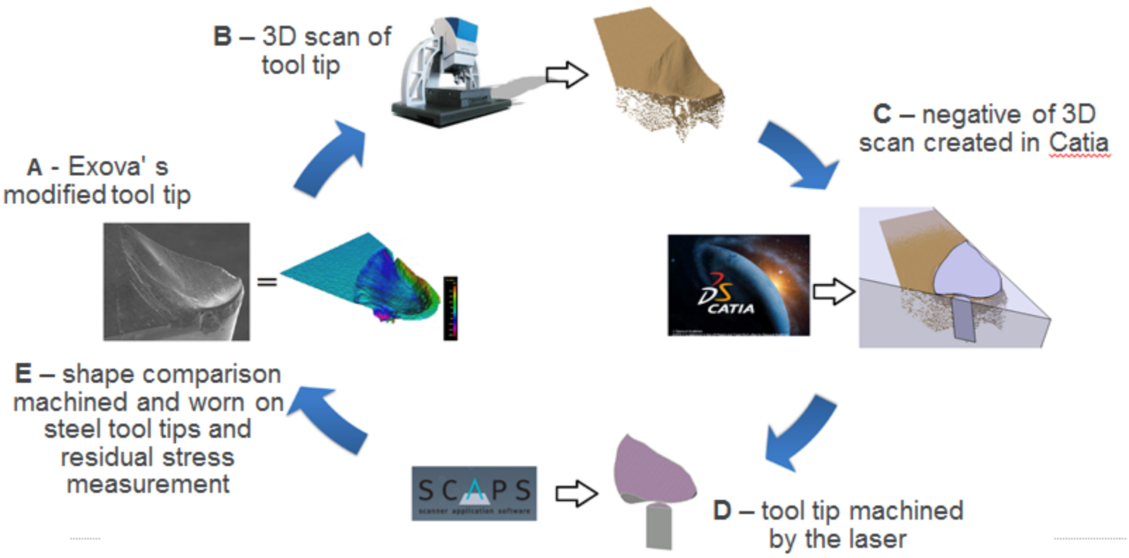

Fig. 5 Process from the wearing of tool tip, up to laser made tool tip [4]

5. RESULTS

During the research process more than fifteen different tool tips were tested as supplied by many suppliers. Twenty polishing, ten machining methods and their combinations were used and tested. Up to now were performed 120 residual stress measurements after machining and polishing too.

When we started the cooperation with the Hofmeister company, we started scan all tool tips after their modification. Exova modified (worn) appx. 50 tool tips. Specimens were turned by these tool tips and residual stresses were measured. Depends on results we chose some tool tips, which were scanned and the shapes were compared. Based on shape similarities, we defined the shape for modification by laser. After the laser modification shapes were compared, specimen machined and residual stress measured again. On Fig.6 are two scanned tool tips modified by Exova and two by Hofmeister. Tool tips 14E and 19E worn by Exova had smooth tool face. One of the first laser modified 13H tool face was very rough. During the time Hofmeister bought new laser with better resolution and optimal parameters for the modification. One of the latest laser modified 31H tool face is comparable with 19E tool face.

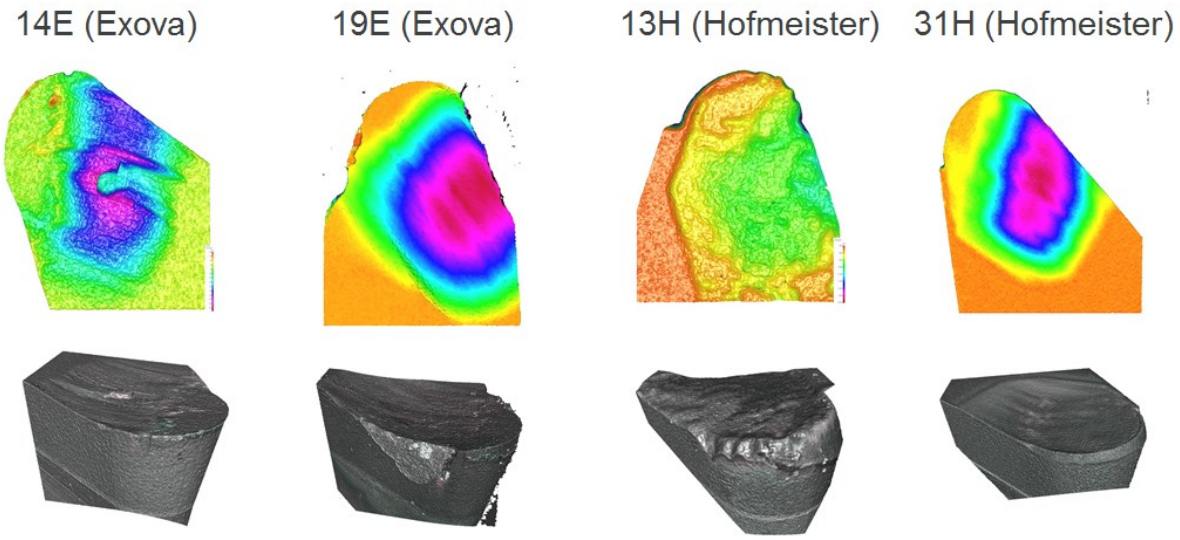

Fig. 6 Scanned tool tips

Because the residual measurement is expensive, we would like to find correlation between surface rougnes and residual stress after turning. We decided to scan the surface on an turned area in a range 1x3 mm and measure area surface rougness. We recieved from each measuremnt appx. 20 values, which describe the area surface roughness. On fig. 7 are surface roughness areas for four modified tooltips described above. Based on available small number of results, it is not possible exactly describe the relationship between area surface rougness and residual stress right now.

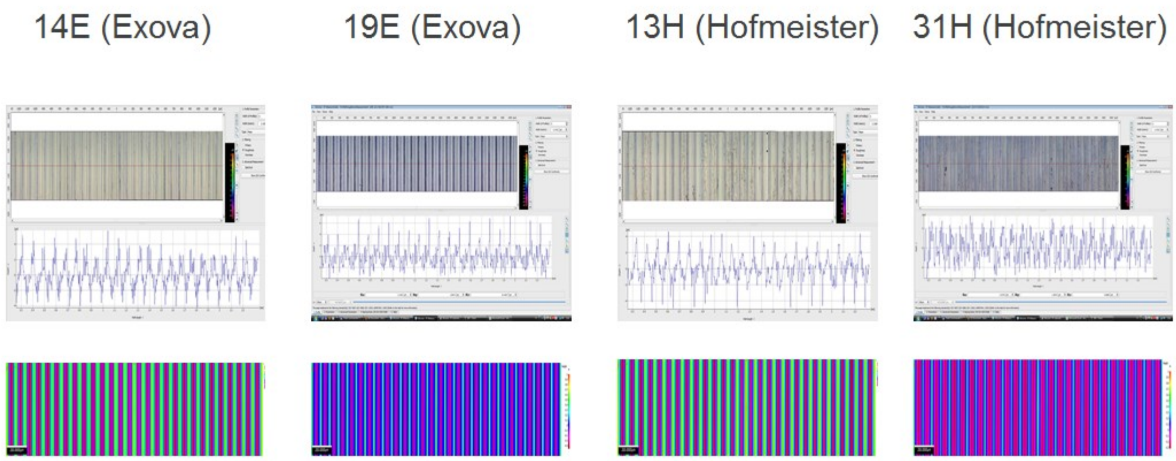

Fig. 7 Area surface roughness

Hofmeister modified more than 30 tool tips. By each one one specimen was turned and residual stress was measured. Results are shown on fig.8. The first tool tips showed high scatter between σ_L and σ_T . During the time the process was improved and scatter was reduced. We also started polish turned specimen after the first residual stress measurement. The differences between turned and polished values indicate that the residual stress in a depth under the surface has different profile. It was removed appx 50 μm thick layer during the polishing. It always increased the residual stress compared to turned specimen.

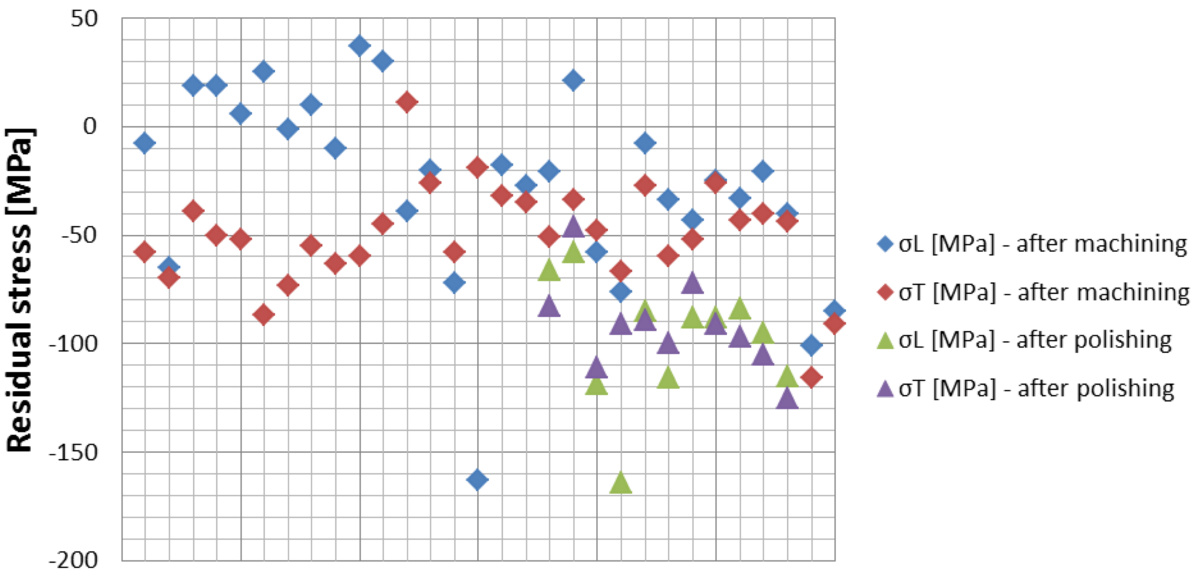

Fig. 8 Process from the wearing of tool tip, up to laser made tool tip

CONCLUSION

Our results proved that we are able to carry out testing according to client´s needs. Based on our experience and residual stress measurement, we are able to guarantee the failure from an internal defect (porosity, inclusions…). We can produce required tool, even if shape function is still not fully understood. We are able also to produce tool tips, which will roughly make required residual stress in surface after turning. By using a different geometry we are able to produce the residual stress between +50 up to -300 MPa.

We still have some challenges to solve:

- Repeatability of the tool tip modification by laser

- Surface roughness after machining

- Depth function of residual stress

- Tool life

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