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Analysis of Operation of a Driving Band Mounting in a Projectile's Shell

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Abstract. The paper presents computational modelling using the Finite Element Method (FEM) for technological operation of a driving band mounted in a groove of a projectile shell. Exemplary results of analysis for shrapnel cal. 35 mm are given. The analysis showed significant factors influencing the mounting process and a field of residual stresses in a projectile shell. It allowed for determination of mechanical properties of materials of a driving band and a projectile shell as well as of characteristic dimensions of half-finished product of a driving band and a groove in a projectile shell. The obtained investigation results show substantial advantages of such analyses for a design process of new types of gunnery ammunition.

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Thus, it is possible to optimise the construction and technology, i.e., to minimise the reduced stresses in a field of residual stresses in a projectile shell what limits the possibility of a driving band break (rupture) or cracking a projectile shell inside a barrel during the shot.
Keywords: mechanics, gunnery ammunition, driving band

1. INTRODUCTION

Basic functions of a driving band are: imparting rotational motion of a gunnery projectile along its longitudinal axis, seal of the space behind a projectile's bottom in a barrel tube and determination of the initial position of a projectile in a cartridge chamber, after projectile load when a cartridge is of separate loaded type, i.e., assembled one. Moreover, with no back-centre-thickness, the driving band ensures centering a rear part of the projectile in relation to the barrel tube's axis. Here, one should notice that the first of the mentioned functions does not concern the case of shooting the projectile with stabilizing fin from a smooth-bore barrel. In practice, cooperation of the driving band with the barrel is a decisive factor for a range and accuracy of projectiles fire as well as for barrel survivability. In extreme cases, faulty collaboration of these elements can cause the driving band's break or the projectile's shell cracking during the shot.

Metal driving bands are placed in a groove of the projectile shell by cold crimping (neck forming) technology using a press equipped with special tools as illustrated in Fig. 1.

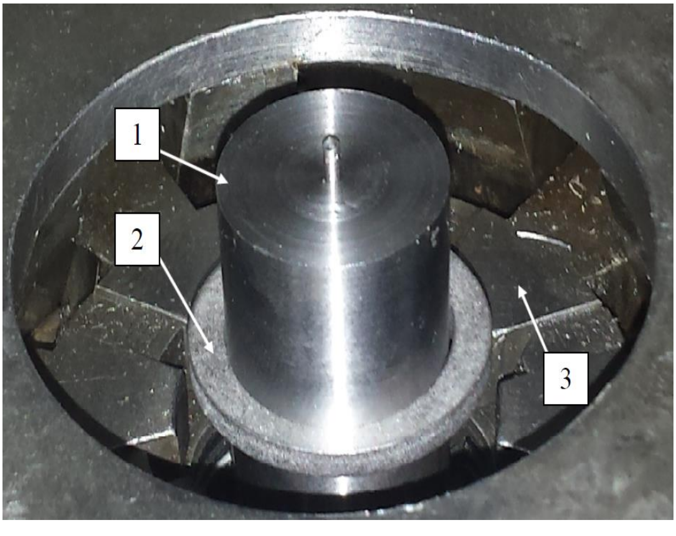

Fig. 1. A device for projectile's shell bending (courtesy of MESKO S.A.): 1 – projectile shell half-finished product; 2 – driving band half-finished product; 3 – clamps

Quality of the projectile's shell banding depends on adequate selection of technological parameters. Figure 2 shows the pictures of cross-sections of projectile shells' fragments with the mounted driving bands.

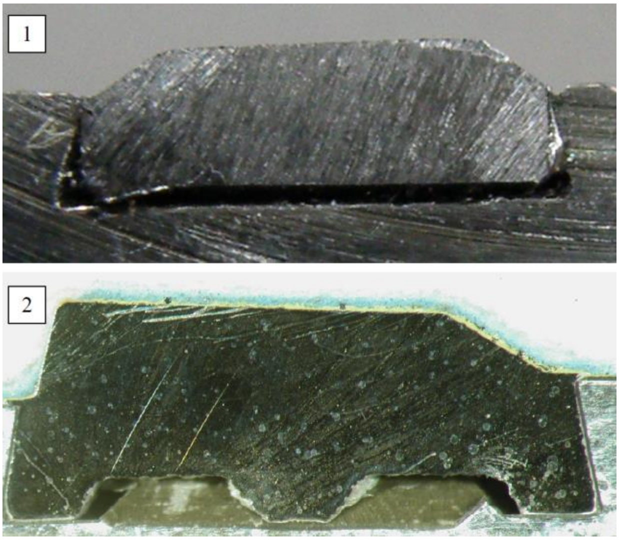

Fig. 2. Cross sections of projectile shell fragments with driving bands:
1 – incorrect banding; 2 – correct banding

For incorrectly mounted driving band, a large slot between internal and external surfaces of the driving band in the shell groove can be seen. Field tests showed that this was the reason of breaking the driving band during the shot. Because of this fact, the investigations on projectile's shell banding were undertaken. Unfortunately, no reports on modelling and theoretical works of technological operation of the banding process were found during literature overview. Majority of available papers concerns the principles of design and calculations of driving bands [1-4], general information on banding technology [5, 6], or collaboration of a driving band with a barrel during the shot [7-12].

Further part of our work presents modelling of technological operation of driving band banding in a groove of a projectile shell with the Finite Element Method (FEM). Also, exemplary results of analysis of the projectile of a shrapnel type, cal. 35 mm are given.

2. GEOMETRICAL MODEL

At the bottom of a pocket for a driving band there are teeth made by knurling with A1.6. knurl in a groove of a projectile shell. Thus, lateral surface of teeth is an envelope of subsequent positions of a tool. Figure 3 shows the results of simulation of the tool's movement and a resulting shape of teeth.

In a geometrical model, an outline of lateral wall of a tooth was approximated with an arc of a radius of 5.16 mm what ensured very good approximation of surface convexity because an approximation error did not exceed 0.5%.

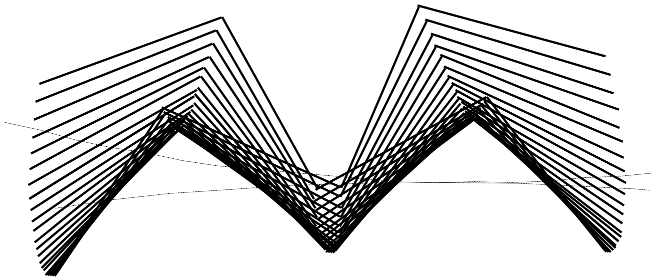

Fig. 3. Positions of the tool's outline during straight knurling in the groove on the projectile shell

To limit the task, a fragment of the shell was analysed, i.e., its part close to the groove made for a driving band. It was assumed that the symmetry plane is in the middle of the groove width. A fragment of an obtuse angle of two teeth was cut on the shell's perimeter. Interaction of the cut fragments of the shell and driving band ensured adequately chosen boundary conditions for displacements. A geometrical model of the system – driving band and the projectile shell, taken for analysis, is shown in Fig. 4.

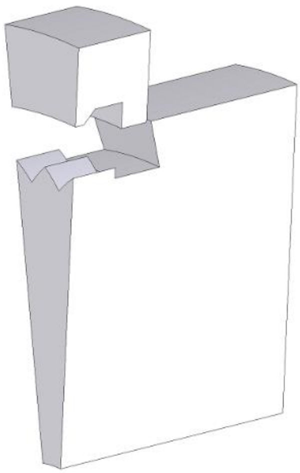

Fig. 4. Geometric model of the driving band – projectile shell system

3. FEM COMPUTATIONAL MODEL

The problem has been solved as a nonlinear statistical task with contact surfaces using ADINA system. FEM net, spanned on a geometrical model, consists of 5155, 10-node spatial elements. Total amount of nodes was 8718. Figure 5 shows computational model with visible division into finite elements.

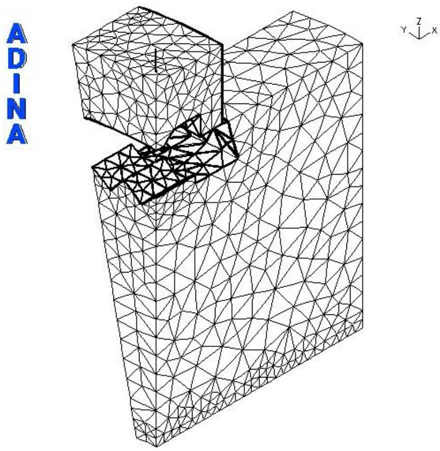

Fig. 5. FEM computational model – contact surfaces marked with heavy line

For the driving band and the shell, elastic-plastic material with nonlinear strengthening was assumed. Its properties were adequate to average values determined during tensile strength investigations of samples in a testing machine. In the described example, the driving band was made of ingot iron and the projectile's shell of the enhanced aluminum alloy of PA type.

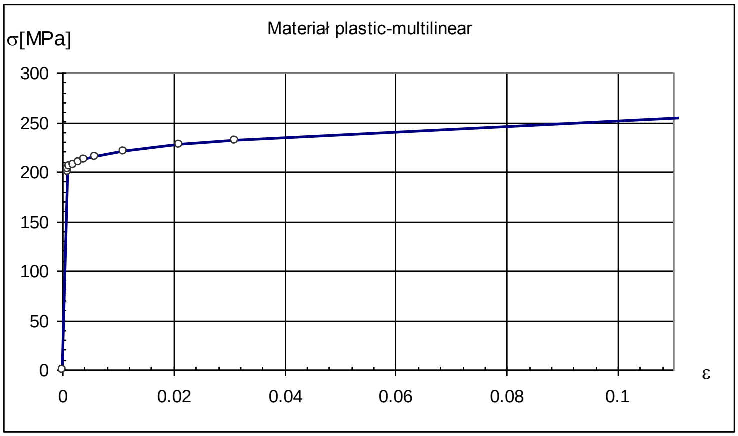

Fig. 6. Stress-strain curve for the driving band material

Figures 6 and 7 show, taken for calculations, enhancement curves for the driving band and shell materials in the engineer coordinates σ-ε.

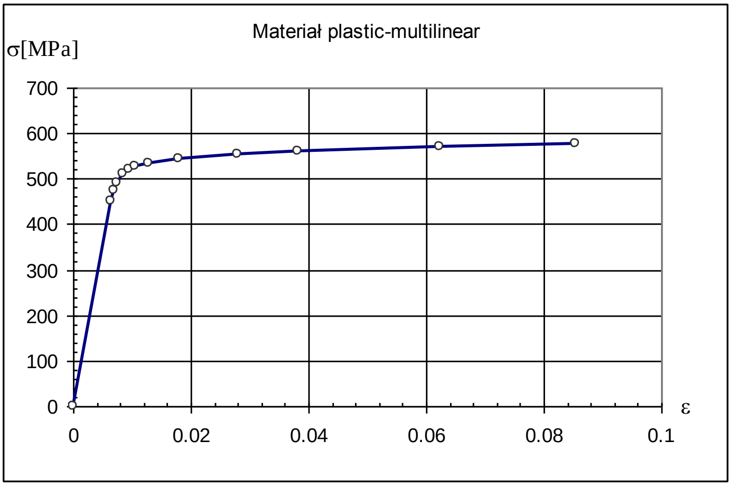

Fig. 7. Stress-strain curve for the projectile shell material

4. RESULTS OF NUMERICAL CALCULATIONS

The calculations were done in 70 iteration steps with gradual increase in pressure on the outer surface of the driving band up to the value of 665 MPa. The results of calculations are given in a graphical form in subsequent figures. Relation between radial displacement of the outer band's surface (absolute value) and the pressure on that surface is shown in Fig. 8.

Figure 9 presents a scheme of mutual positions of the connected parts and accompanying deformation as a function of increasing values of pressure on the band's outer surface (necking pressure).

Figure 10 shows a field of the reduced stress and plastic deformations area for the necking pressure p = 456 MPa and Fig. 11 shows the same values for the pressure p = 664 MPa. Comparing these two figures, one can see significant increase in the area of plastic deformations together with increase in the necking pressure.

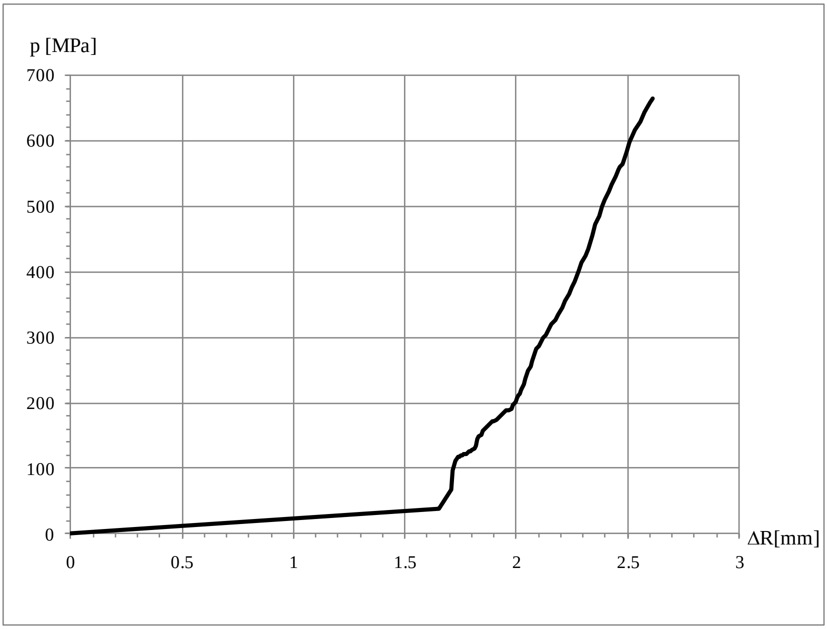

Fig. 8. Relationship between radial displacement of the band's outer surface and pressure on that surface

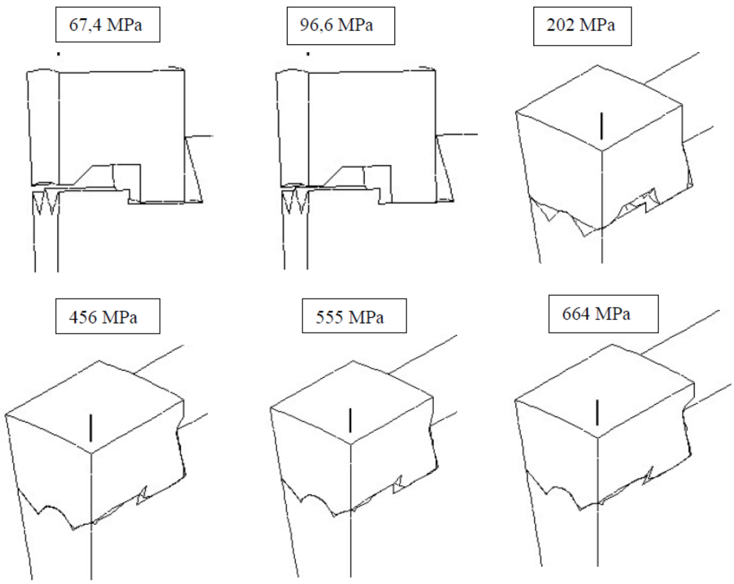

Fig. 9. Mutual positions of the band and the projectile shell with pressure values on the band's outer surface (necking pressure)

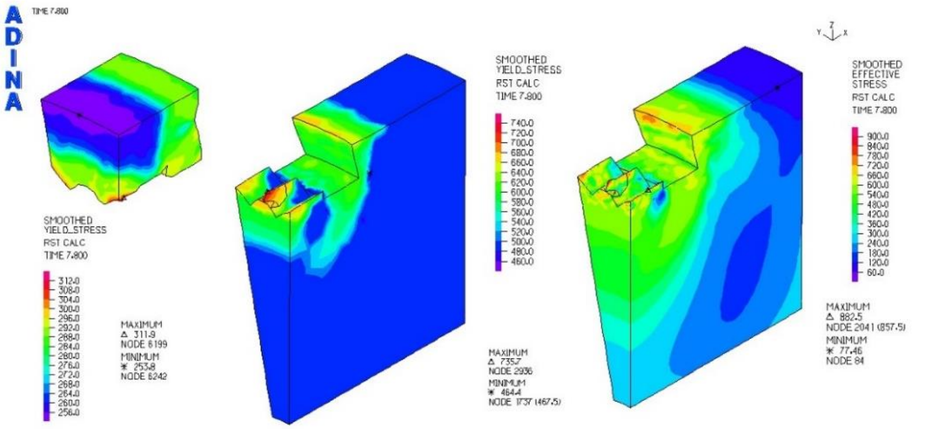

Fig. 10. Reduced stress field and plastic deformations area for necking pressure p = 456 MPa (non-plasticized area in the middle part coloured dark blue)

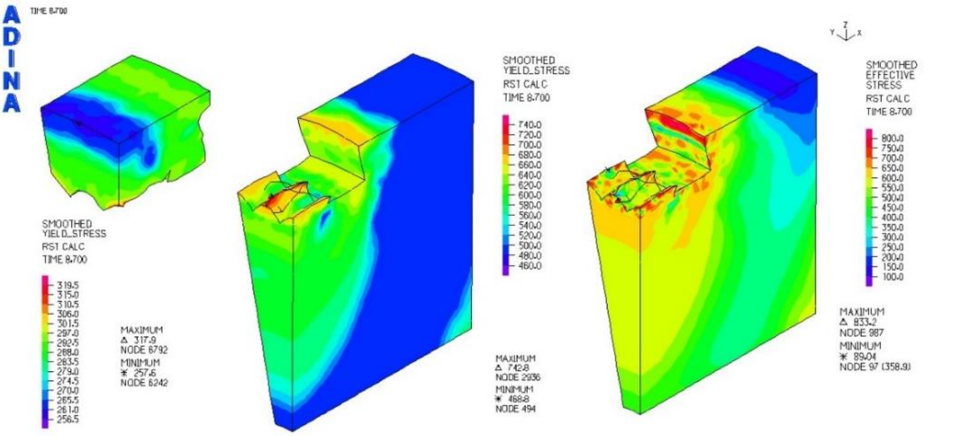

Fig. 11. Reduced stress field and plastic deformation area for necking pressure p = 664 MPa (non-plasticized area in the middle part coloured dark blue)

The obtained results show that increase in the necking pressure does not cause improvement in quality of the driving band mounted in the groove of the projectile shell because the band’s material still does not totally fill the groove in the shell and it is accompanied by significant increase in plasticity of the area in the projectile shell what is disadvantageous from the point of view of loads during the shot. It results from the fact that during further loss treatment of half-product of the banded projectile’s shell, this area significantly influences the resulting field of residual stresses.

Particular components of these stresses, superimposing the components of the stress, produced as a result of the loads occurring during the shot, can cause, in the extreme case, exceeding the strength of the projectile's shell material and its cracking.

Moreover, incomplete banding in the groove can cause break of the driving band. The result of it can be too small rotational velocity of the projectile at the muzzle, what can lead to decrease in fire range and accuracy (higher ballistic scatter).

Analysis of the results of the carried-out simulation allowed to propose modification of a shape of the driving band's half-finished product in order to have the required quality of connection between the band and shell at lower necking pressure. This modification consisted in inclination of the fragment of the driving band's inner surface at the angle α, what is shown in Fig. 12.

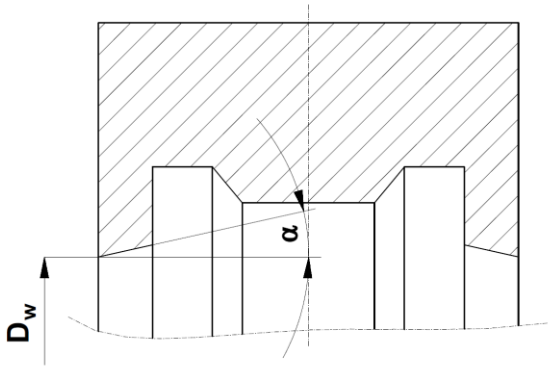

Fig. 12. Proposed modification of the driving band's inner surface (half-finished product)

The introduced correction of the FEM's geometrical model is illustrated in Fig. 13. On this modified model, new net, having identical finite elements to the previous ones, was spanned and other parameters and characteristics of the model were the same.

The calculation results are presented in the next figures. Relation between radial displacement of the outer band's surface and necking pressure is shown in Fig. 14. It turned out, that in this case the pressure equal to 337 MPa is fully sufficient for proper mounting the driving band in the groove of the projectile shell.

Figure 15 (on the left): mounting the driving band in the groove, plastic deformation area and distribution of stresses reduced in the projectile's shell. Dark blue area in the middle of illustration is a non-plasticised area. In the described case, the area of plastic deformations is practically near the teeth and the edge of dovetail joint. Thus, the driving band is properly mounted in the groove.

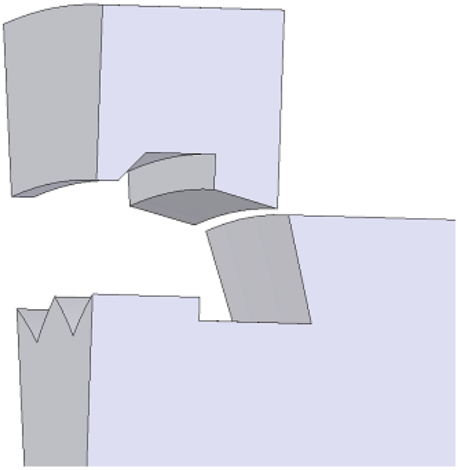

Fig. 13. Fragment of a geometrical model after change of the driving band's geometry

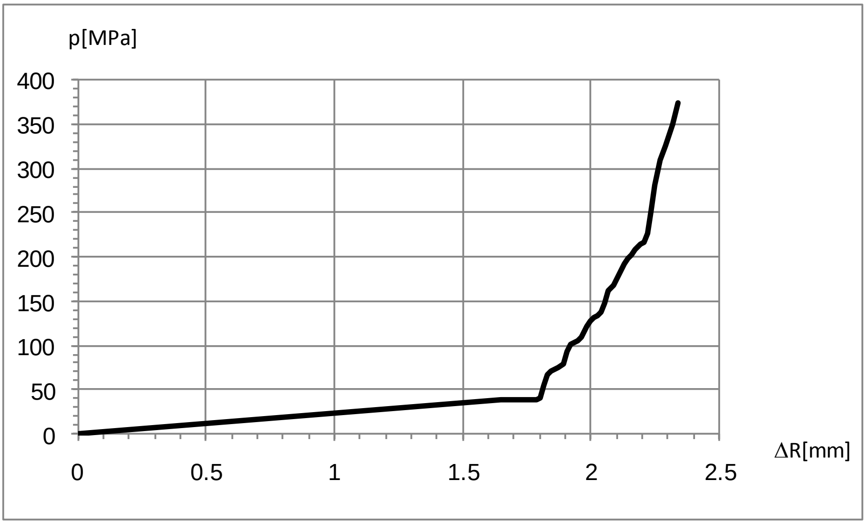

Fig. 14. Relationship between radial displacement of the band's outer surface and necking pressure for the modified shape of the band

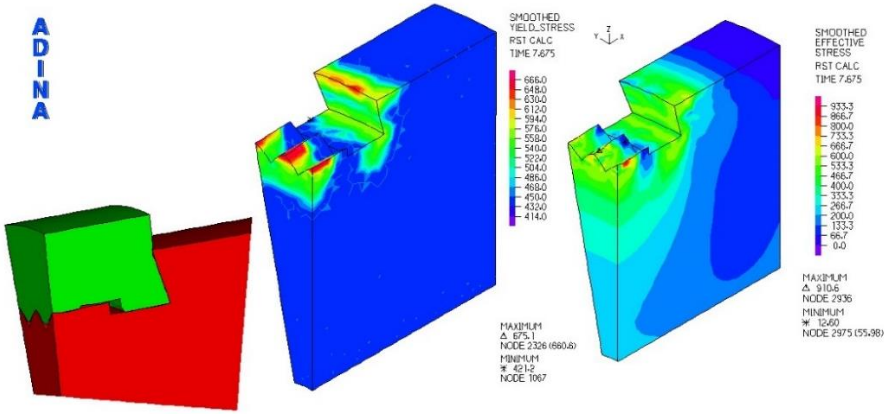

Fig. 15. Mounting the band in the groove, plastic deformations area and reduced stresses in the projectile shell for the necking pressure p = 337 MPa

5. SUMMARY AND CONCLUSIONS

The presented modelling with finite elements method of technological operation of the driving band mounted in the groove of the projectile's shell fully confirms usefulness of such analyses for design process of new ammunition types. Essential advantage is the possibility of optimisation of design and technology, i.e., minimisation of substitute stresses in the area of residual stresses in the projectile's shell. Due to it, one can limit the possibility of the driving band breaking or cracking the projectile shell inside the barrel during the shot.

The analysis showed that significant influence on the course of driving band mounting and on the area of residual stresses in the projectile's shell has the shape of a half-product of the driving band. Inadequate shape of inner surface of a half-product of the band usually causes its improper mounting in the groove in the projectile's shell. Only increase in the necking pressure does not improve the result of mounting operation because still there are voids near the groove's corner what is illustrated in Fig. 16.

Only the inclined fragment of the inner band's surface, as it can be seen in Fig. 12, allows for decrease in a value of the required necking pressure of about 50%. Also, significant decrease in the area of plastic deformations in the projectile's shell can be observed, which in practice comprises only the close vicinity of the knurling part of the groove (Fig. 15).

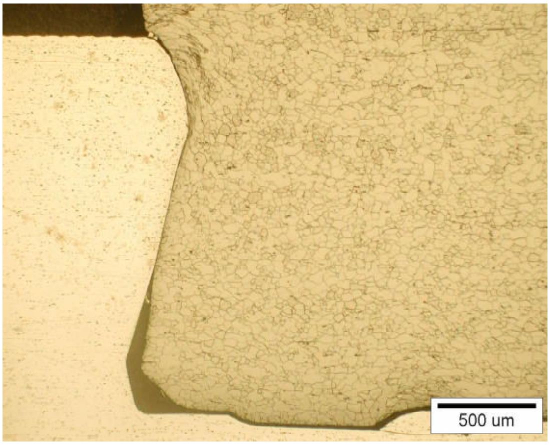

Fig. 16. Fragment of cross-section of half-finished product – banded shell

Further works in this range should be focused on the development of the FEM model comprising also the operations of loss treatment of the banded shell. Computer simulation for such a model will allow for quantitative estimation of residual stresses in the projectile's shell which occur during the projectile production.

Concluding, one can state that such analysis is especially useful when the projectile's shell should have the possibly lowest mass, e.g., in the shrapnel type projectiles. Then, the shell is made of the aluminum alloys having relatively low strength. Additionally, the shell shaping is subjected to achieve its minimum mass. Thus, decrease in residual stresses in the shell, that are introduced during its production, can have significant influence on functionality of the whole projectile.

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Analiza operacji osadzania pierścienia wiodącego w skorupie pocisku

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Streszczenie. W pracy przedstawiono sposób modelowania metodą elementów skończonych (MES) operacji technologicznej osadzania pierścienia wiodącego w rowku skorupy pocisku. Zamieszczono przykładowe wyniki analizy dla pocisku typu szrapnel kal. 35 mm. Analiza pozwoliła wskazać czynniki mające zasadniczy wpływ na przebieg opierścieniania i pole naprężeń szczątkowych w skorupie pocisku. Dzięki temu było możliwe ustalenie wymagań: dla właściwości mechanicznych materiałów pierścienia wiodącego i skorupy pocisku oraz parametrów technologicznych operacji osadzania pierścienia, jak również kształtu i charakterystycznych wymiarów: półwyrobu pierścienia wiodącego i rowka w skorupie pocisku. Otrzymane wyniki badań wskazują na istotne korzyści z prowadzenia tego typu analiz w procesie projektowania nowych wzorów amunicji. Dzięki temu możliwa jest optymalizacja konstrukcji i technologii, polegająca na minimalizacji naprężeń zastępczych w polu naprężeń szczątkowych w skorupie pocisku, która ogranicza możliwość wystąpienia zerwania pierścienia wiodącego lub pęknięcia skorupy pocisku wewnątrz lufy podczas strzału.

Słowa kluczowe: mechanika, amunicja artyleryjska, pierścień wiodący