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ANALYSIS OF DIE DESIGN FOR THE STAMPING OF A BATHTUB

ANALIZA PROJEKTU NARZĘDZI DLA PROCESU TŁOCZENIA WANNY

The paper presents example results of numerical and photogrammetric analysis leading to identify the causes of cracking and wrinkling during bathtub W1200 production. The verification of tools for the stamping of bathtub W1200 was performed using finite element method and photogrammetric system ATOS Triple Scan. A series of industrial tests was conducted to identify the model parameters. The major and minor strain distributions obtained from the finite element simulations were used in conjunction with the forming limit diagram to predict the onset of fracture. In addition, the effects of blank holder pressure and friction on the occurrence of fracture and wrinkling were investigated.

Keywords: deep drawing, bathtub, restraining force, geometrical drawbead, finite element method

W artykule przedstawiono przykładowe wyniki analiz numerycznych i fotogrametrycznych mających na celu identyfikację przyczyn powstawania fałdowania i pęknięcia wanny serii W1200 w trakcie cyklu produkcyjnego. Weryfikacja narzędzi przeznaczonych do tłoczenia wanny W1200 została przeprowadzona przy użyciu metody elementów skończonych oraz precyzyjnego systemu fotogrametrycznego ATOS Triple Scan. W trakcie prac badawczych przeprowadzono cykl procesów nadzorowanych procesu produkcyjnego mającego na celu identyfikację parametrów modelu numerycznego. Odształcenia duże i małe wyznaczone na podstawie symulacji numerycznych w połączeniu z krzywą odształceń granicznych (KOG) pozwoliły na identyfikację krytycznych rejonów wytłoczki narażonych na fałdowanie i pęknięcie. Dodatkowo w trakcie przeprowadzonych prac przeanalizowano wpływ warunków tarcia oraz nacisku w kontekście powstawania fałdowania i pęknięcia wytłoczki.

1. Introduction

In the last years, in the technology of sheet metal forming has undergone a number of innovative changes such as new forming technique and application of advanced computer technology [1]. One of the computer technologies is the Computer Aided Engineering (CAE). Computer Aided Engineering refers to a system of computerized analytical tools that permit finite element analysis of effective stresses, equivalent plastic strains, deformation, thickness distribution, temperature distribution. The main goal of CAE is to bypass the costly experimental testing, using fast, low cost and accurate computer simulation. CAE allows engineers to simulate and study characteristics of product during design and development cycle, as well as production. Information obtained from application of CAE helps to refine and optimize product design and manufacturing of products.

The paper presents example results together with accompanying problems leading to identify the causes of cracking and wrinkling during bathtub W1200 production. The efforts focused on the die verification for the stamping of a bathtub are mainly to avoid major defects such as wrinkling and fracture. Successful die verification generally results from an accurate prediction of the metal flow during the forming process and

on the other hand on the experience and know-how of engineers in actual practice. In order to eliminate wrinkles without introducing fracture, the effects of the blank holder pressure, friction, and the distribution of the drawbead especially restraining force were investigated also. On the other hand, in order to die digitalization for simulations purposes and checks quality of stamping die (especially tooling flatness), the industrial high-end 3D digitizer was used.

2. Inspection of tools

The inspection of tools with using photogrammetric systems was carried out. Photogrammetry is a versatile, powerful, and flexible measuring technology and is widely used in the aerospace, shipbuilding, construction, and automotive industries for a wide variety of measurement tasks [2,3]. Due to fast development the area in which they are used, is continuously expanding. Optical measuring systems can be divided into two distinctive groups. The first is the spatial systems for digitizing objects, the second is the systems to analyze the deformation – both in terms of static and dynamic. Systems of optical, spatial scanning (digitization) are used to create technical documentation of tools based on the existing physical objects, obtaining data for the numerical modeling and

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simulation, and quality control of tools [4]. Photogrammetric techniques are also increasingly used not only in industry but also for example in medicine [5,6].

The measurements were performed using ATOS Triple Scan (Fig. 1). The mentioned system uses a specially developed measuring and projection technology from GOM. GOM is a global industry partner, developing and producing optical measurement solutions and technologies for 3D coordinate measurement and deformation analysis. Using this brand new technology, the ATOS Triple Scan produces a high accuracy and improved measurement of shiny surface, complete data on complex components with deep pockets or fine edges such as turbine blades, reducing the number of individual scans and resulting in a simple handling. System is also equipped with blue light technology. The narrowband blue light enables precise measurements to be carried out independently of environmental lighting conditions. ATOS uses high resolution measuring cameras with up to 12 megapixel resolution and specially developed optics for precise measurement. The accuracy, measurement resolution and measuring area are completely adaptable to the application requirements. This allows for the highest resolution for highly detailed, small parts with measuring volumes up to 38 mm, or for extremely fast digitizing of large objects with measuring volumes up to 2 m.

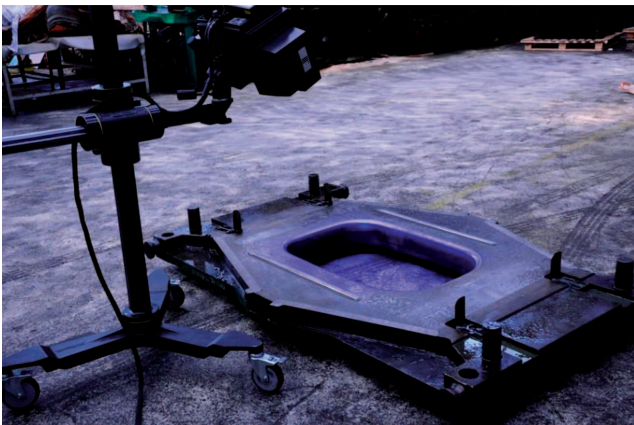


Fig. 1. ATOS Triple Scan during die scanning

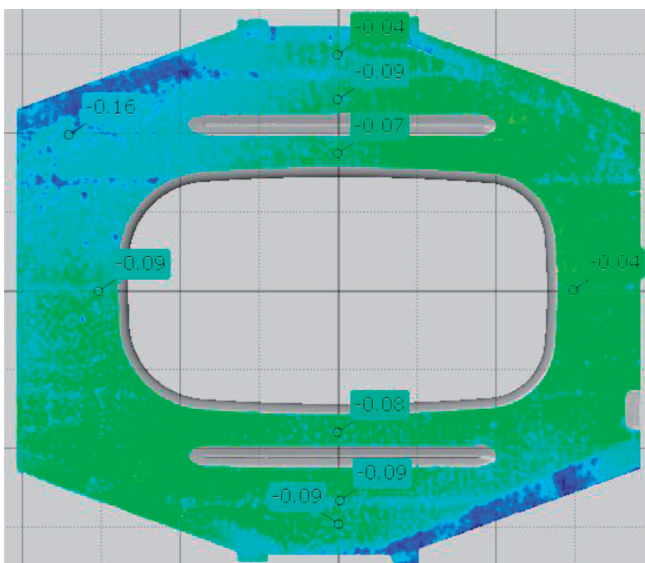


Fig. 2. Measured flatness of die

Analyses of tools flatness were made using software GOM Inspect V7.5 SR1. Measurements accuracy was set to 0.03 mm. The color map of measured flatness of die and binder are presented in Figure 2 and Figure 3, respectively. Analyzing the flatness of the die (Fig. 2), we can observe that maximum and minimum value deviation is in the range from -0.16 mm to -0.04 mm. Similar situation was observed during analysis of binder (Fig. 3), where maximum and minimum deviation is in the range from +0.25 mm to -0.24 mm.

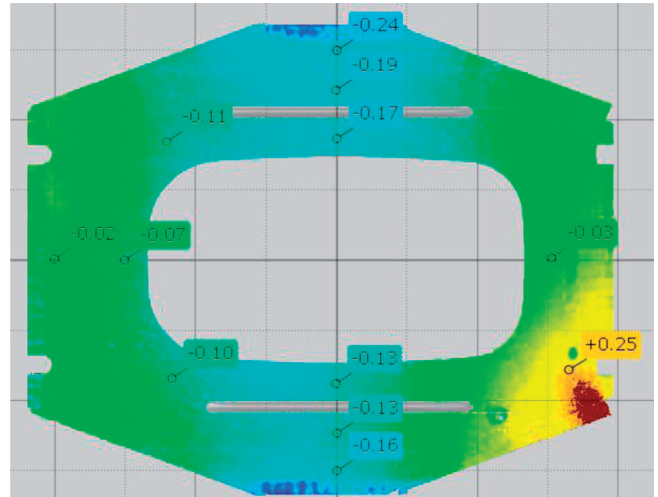


Fig. 3. Measured flatness of binder

In the next step mutual adjustment tools (die / binder) was checked. Measurements were made for fourteen log points, denoted L1-L14, as shown in Figure 4.

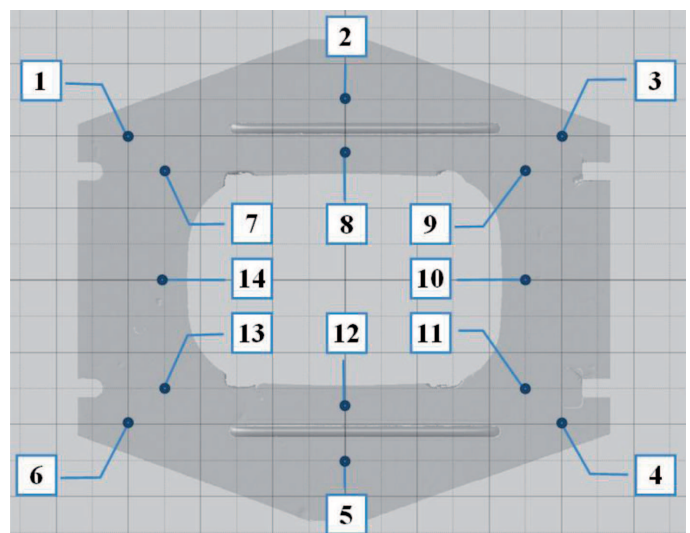


Fig. 4. Sample geometry and the location of the various log points (L1-L14)

Example results of the measurements of both matching tools are presented in Figure 5. As can be seen in the graph, the flatness of the tools is not maintained. This is the main reason why during the manufacturing process occurred to cracking and wrinkling. Lack of tools flatness was compensated using non-uniform pressure during real technology process. On the other hand, this approach has resulted in variable local deformation conditions: higher local pressure and friction condition.

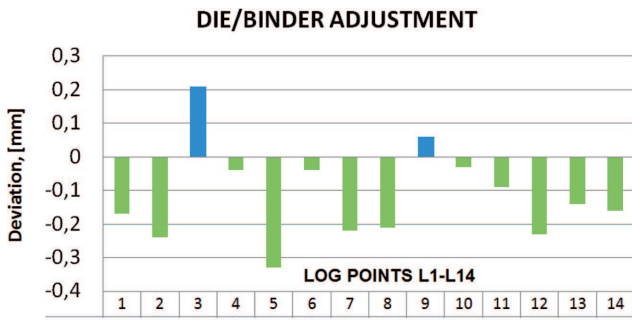


Fig. 5. Die versus binder after fitting of tools.

Fig. 5. Die versus binder after fitting of tools

3. Mechanical properties

The stamped bathtub is made of DC05 grade steel of 1.3 mm thickness and is to be formed by a single drawing process to avoid drawing marks caused by a multi stamping process. Also, both the flange width around the cavity and maximum thinning of the final shape should be greater than 70 mm and lower than $\pm 40\%$, respectively, required by the technology process. An accurate finite element analysis of stamped metal parts requires the actual stress-strain relationship of the sheet metal as part of the input data. The specimens were cut along planes coinciding with the rolling direction and at angles of 45° and 90° to the rolling direction. The flow stress ($\bar{\sigma}$), for each measured true strain, was used for the finite-element simulations, where σ_0 , σ_{45} and σ_{90} are the flow stresses obtained from the specimens cut along the rolling direction and at angles of 45° and 90° to the rolling direction, respectively. To determine forming limit diagram (FLD) Keeler formula was used. Since Keller introduced the concept of the forming limit diagram in 1964, it has been a widely accepted criterion for fracture prediction in sheet metal forming. In practice, the failure curve moved down by 10-15% was used as the design curve, as shown in Figure 6.

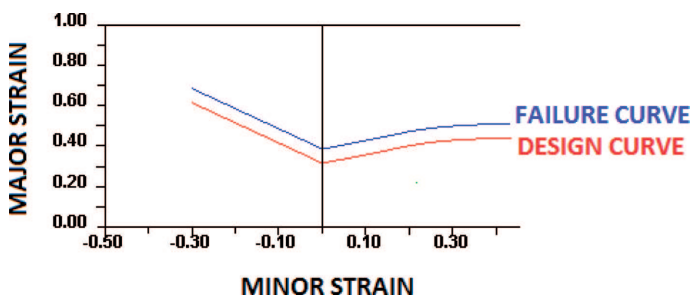


Fig. 6. Forming limit curves (DC05 grade steel)

In the numerical simulations an anisotropic Barlat model was used. The other process parameters, such as the friction coefficient and blank holder pressure, were set differently for the different stamping conditions.

4. Finite-element model

In the present study, the tooling setup for the stamping of a bathtub W1200, as shown in Figure 7, was investigated using three dimensional dynamic/explicit finite element analyses.

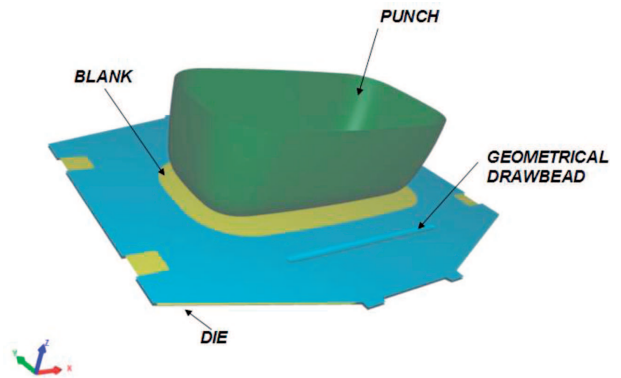


Fig. 7. Tooling setup for the stamping of a bathtub W1200

The final part geometries measured by a ATOS Triple Scan for the initial die design were provided by the GOM Inspect system. In the finite element simulation, the tooling is considered to be rigid. The condition contact proceeding during stamping of bathtub was identified by algorithms coded in explicit solver. In the analysis process, the sheet was pulled through drawbeads which are very often used in the forming technology. Their proper shape and positioning require multiple and time-consuming computer simulations. In this paper, the geometrical drawbeads was used (Fig. 8a). Drawbeads allows such forming to flow resistance of the material were distributed evenly. They meet the very important role of causing additional tensile stress, which prevents the formation of wrinkles on the surface of the drawpiece [7]. Drawbeads should be modeled as a large number of the smallest elements in order to reflect more accurately the effects of transitions metal. Simulations with geometrical drawbeads are very time consuming, so very often, in numerical analysis, effective model of drawbeads are introduce (Fig. 8b). The restraining force exerted by the actual drawbead is assigned distributely to the nodes in the regular mesh of the equivalent drawbead. The assigned restraining forces are then assumed to act on the sheet metal which moves through these nodes. Such operation allows simulation time reduction without influence on very good calculation accuracy.

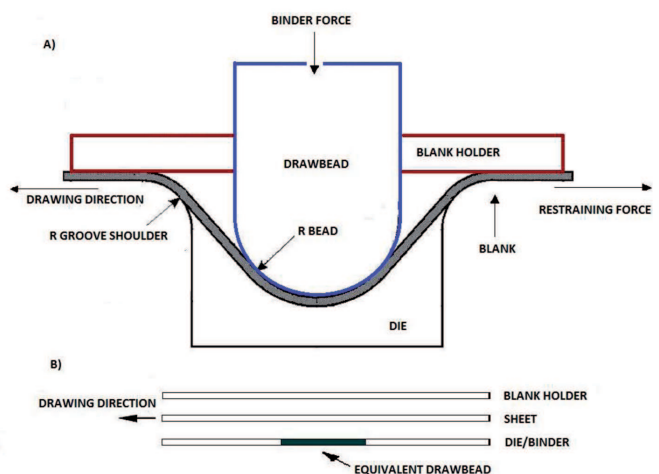


Fig. 8. Drawbead models: (a) geometrical, (b) equivalent

More details about bathtub die modeling with using equivalent drawbeads is presented in publications [8-11].

5. Results of computer simulations

The analysis of the original die design was performed according to the pattern of metal flow obtained from the finite element simulations. In addition to the die face verification, computer simulations were also conducted to study the effect of the process parameters such as friction and blank holder pressure, on the formability of the bathtub stamping process. In the present study two variants of modeling was adopted. For the first, original tools geometry obtained by scanning was used. In this variant the numerical model of binder was founded as flexible. For the second, the numerical model assumed change the pressure distribution on the binder. In this case, the model of binder was treated as rigid. The simulation results are summarized and discusses as follows. A clamping uniform pressure of 1.6 MPa exerted by the blank holder and a coefficient of friction of 0.09 were assumed for the original die design. The final shape that results from which design being show in Figure 9. As seen, significant metal wrinkling appear on the draw wall. The major and minor strain distributions as well as the forming limit diagram are shown in Figure 10. It is seen clearly that the final shape is free from fracture, but the presence of wrinkles are not allowed in the final product. The wrinkles disappear when the blank holder pressure is increased from 1.6 MN to 2.0 MN, according to the simulation results. An increase in friction at the blank-die interface results in the same effect as that of an increase in the blank holder pressure. The presence of wrinkles can be prevented when the coefficient of friction is increased from 0.09 to 0.25. More details about effect of the process parameters such as friction and blank holder pressure, on the formability of the bathtub stamping process can be found in [7].

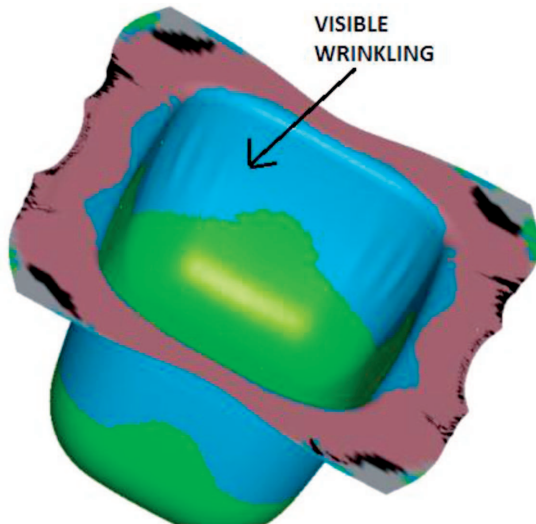


Fig. 9. Final shape of a bathtub W1200 for the original die design (uniform binder pressure)

However, in real industrial process situation was quite complicated. In order to compensate lack of die/binder flatness, the no-uniform binder pressure was applied. A clamping no-uniform pressure of 2.0 MPa to 6.0 MPa range and a friction of 0.09 were assumed for the original die design. The results of real industrial simulations are presented in Figure 11. It is seen that the final shape is free from stamping defects.

However, the major and minor strain distributions plotted on the forming limit diagram, as shown in Figure 11, indicate that the sheet metal is close to fracture since many of the points are near the risk of crack line (design line).

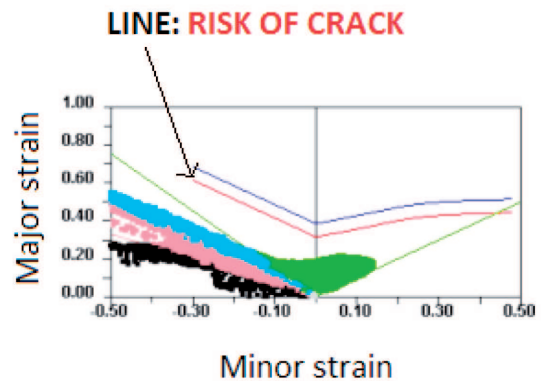


Fig. 10. The minor and major strain and Forming Limit Diagram (FLD) for the original die design (uniform binder pressure)

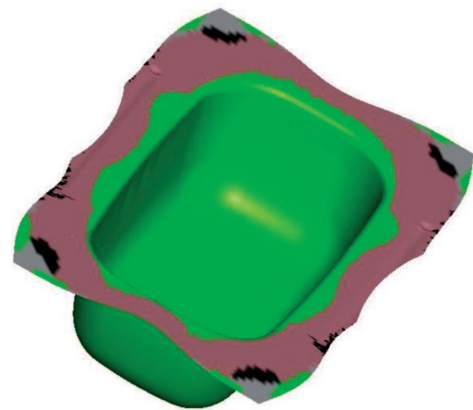


Fig. 11. Final shape of a bathtub W1200 for the original die design (real industrial process with no-uniform binder pressure)

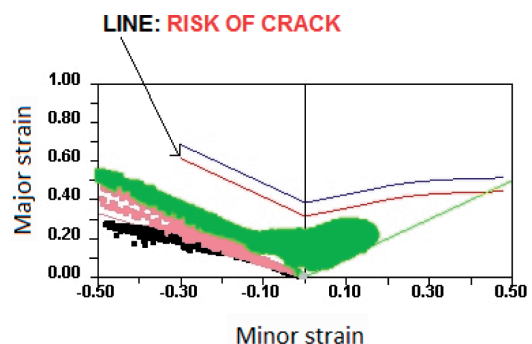


Fig. 12. The minor and major strain and Forming Limit Diagram (FLD) for the original die design (real industrial process with no-uniform binder pressure)

As predicted by the finite element analysis, the production part is free from defects. The Figure 13 shows the contour of final shapes from simulations and industrial tests. The final shape of bathtub is quite correct with the shape obtained by computer simulations.

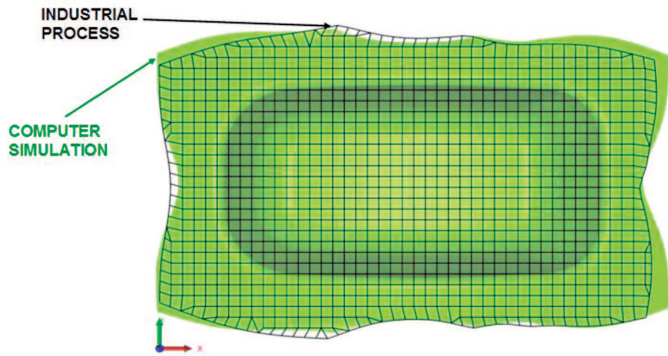


Fig. 13. Comparison of the final contour of a bathtub W1200 with contour obtained from finite-element simulations

In the Figure 14 and figure 15 the final shapes from simulations and industrial test of a bathtub W1200 for the original die design with marked wrinkling area near geometrical drawbead are presented, respectively. This confirms the benefits of using FE systems to verifications tools in stamping industry.

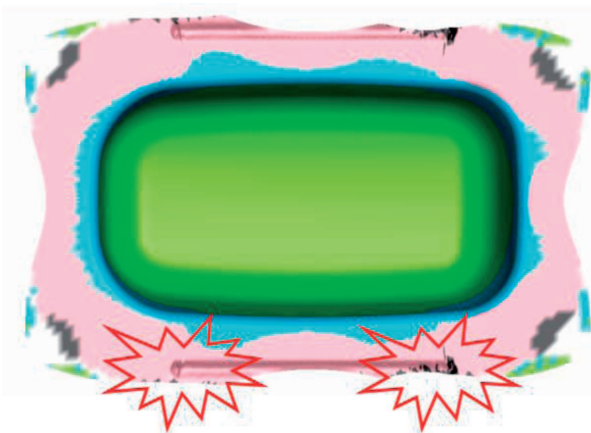


Fig. 14. Final shape of a bathtub W1200 for the original die design (real industrial process with no-uniform binder pressure) with marked wrinkling area near geometrical drawbead



Fig. 15. Photo of final shape of a bathtub W1200 for the original die design with marked wrinkling area near geometrical drawbead

The comparison of the final shape obtained from finite-element simulations and from industrial process is presented in Figure 16. Maximum deviation between both shapes equals 0.11 mm.

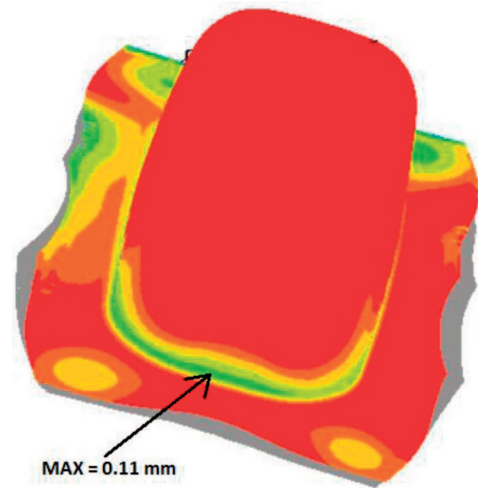


Fig. 16. Comparison of the final shape obtained from finite-element simulations and from industrial process (ATOS Triple Scan)

Precise numerical model will allow for a thorough analysis of stamping process. In the next simulation variant taken into account increasing the friction coefficient. A clamping no-uniform pressure of 2,0 MPa to 6,0 MPa range and a friction of 0.095 were assumed for the original die design. The results of computer simulations are presented in Figure 17. It is seen that the final shape is not free from stamping defects. The major and minor strain distributions plotted on the forming limit diagram, as shown in Figure 18, indicate that the sheet metal fracture since many of the points are above the crack line. The split effect was predicted at the bottom part of bathtub. The same results was obtained during industrial process (Fig. 19).

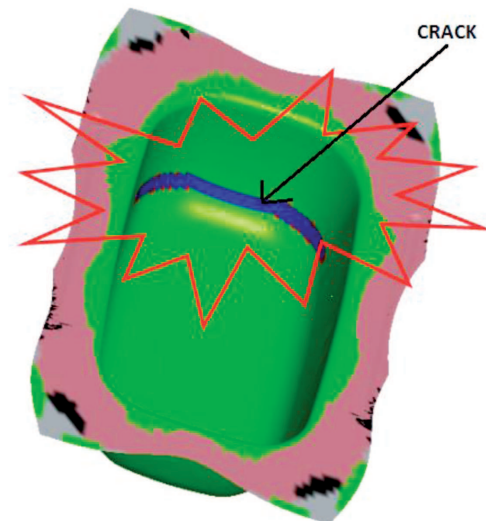


Fig. 17. Final shape of a bathtub W1200 for the original die design (real industrial process with no-uniform binder pressure and higher friction)

Finally, simulations with modified die design were performed. The numerical model assumes flatness tools and uniform pressure of binder. A clamping uniform pressure of 2,0 MPa exerted by the blank holder and a coefficient of friction of 0,09 were assumed for the modified die design. The final shape of bathtub is free from typical defects of stamping process (Fig. 18). Appropriate modification of tools based on

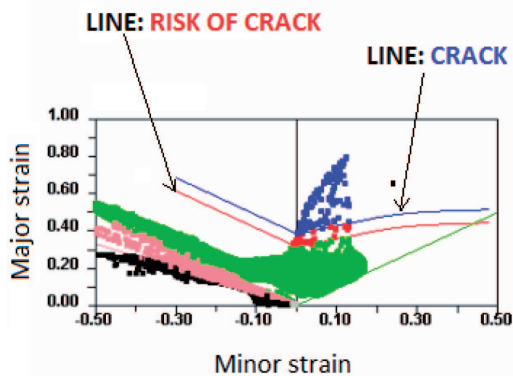


Fig. 18. The minor and major strain and Forming Limit Diagram (FLD) for the original die design (real industrial process with no-uniform binder pressure and higher friction)

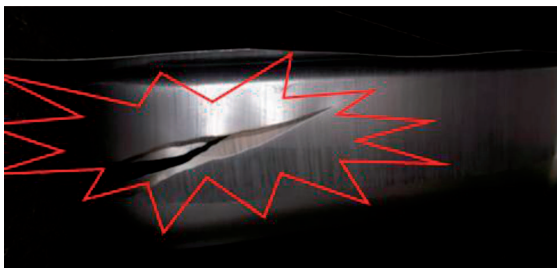


Fig. 19. The split localization after stamping process of bathtub W1200

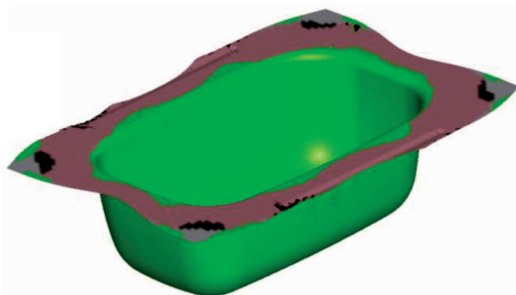


Fig. 20. Final shape of a bathtub W1200 for the modified die design

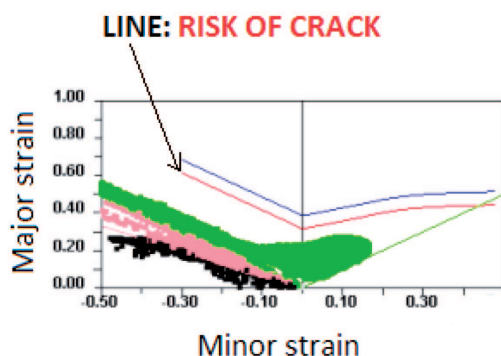


Fig. 21. The minor and major strain and Forming Limit Diagram (FLD) for the modified die design

computer simulations allowed to receive the final part which is in accordance with the objectives of the technological process. As for the major and minor strains computed from the computer simulation, as shown in Figure 19, the corresponding points

are all below the risk of crack line. This indicates that a defect free part can be produced under the stamping conditions.

6. Conclusion

In the present work tools verification for stamping of a bathtub W1200 was investigated using FEM and photogrammetric system ATOS Triple Scan. In the investigation, the cause of the formation of wrinkles and fractures was studied on the basis of the metal flow obtained from the simulation results. The forming limit diagram was also used in conjunction with the finite element results to predict the occurrence of fracture. Analysis of tools in the GOM Inspect system showed, that flatness of die and binder was not maintained. It was main source of problems occurring during production of bathtub W1200. Lack of tools flatness was compensated using higher no-uniform pressure during real technology process. This approach has resulted in variable local deformation conditions, especially higher local pressure and friction condition. The use of a uniform pressure and the application of flatness tools will carry out the process in a safe range of strain (about 10% below design curve).

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