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APPLICATION OF AN INTEGRATED CAD/CAM/CAE/IBC SYSTEM IN THE STAMPING PROCESS OF A BATHTUB 1200 S

ZASTOSOWANIE ZINTEGROWANEGO SYSTEMU CAD/CAM/CAE/IBC W PROCESIE TŁOCZENIA WANNY 1200 S

Nowadays, metal stamping industries have been characterized by a strong demand for reduced development costs and time. Therefore, computer aided product development has become one of the most important techniques in the stamping industry. In the paper, according to the concurrent engineering concept, an integrated CAD/CAM/CAE/IBC system for stamping die is implemented. This system includes, CAD/CAE software PRO/ENGINEER, stamping formability analysis software DYNAFORM, structural analysis software DSA (Die Structural Analysis), CAM software and product database. In order to allow three geographically dispersed teams to simultaneously work on the development of products, the Internet-Based Collaboration (IBC) system to shear design models and analysis results has been developed. The CAD/CAM/CAE/IBC system can greatly reduce the development time and cost, improve the product quality, and push product into the market in a relatively short time. This paper uses the development of a bathtub 1200 S as an example to show the possibility of the system, in which the different development stages can be performed simultaneously.
Keywords: CAD/CAM/CAE system, equivalent drawbead, deep drawing, bathtub, restraining force, concurrent engineering (CE)

W dzisiejszych czasach, przemysł tłoczniczy charakteryzuje się intensywnym poszukiwaniem sposobów na zwiększenie wydajności przy równoczesnym skróceniu czasu rozwoju produktu oraz kosztów. Dlatego też, komputerowe wspomaganie rozwoju produktu stało się jedną z najbardziej istotnych technik w przemyśle tłoczniczym. W prezentowanej pracy, zgodnie z koncepcją inżynierii współbieżnej zaimplementowano zintegrowany system CAD/CAM/CAD/CAE/IBC wspomagający projektowanie narzędzi tłoczniczych. Wspomniany system składa się, z oprogramowania CAD/CAE PRO/ENGINEER, oprogramowania do analiz procesów tłoczenia DYNAFORM, oprogramowania do analiz strukturalnych DSA (Die Structural Analysis), oprogramowania CAM i bazy danych. W celu umożliwienia trzem geograficznie rozproszonym zespołom równoczesną pracę nad rozwojem produktu, opracowano internetowy system (IBC) umożliwiający współdzielenie modeli geometrycznych i wyników analiz. Zaimplementowany system CAD/CAM/CAE/IBC może znacząco zredukować czas rozwoju i koszty, poprawić jakość produktu, i dzięki temu wprowadzić produkt na rynek w względnie krótkim czasie. W prezentowanym artykule rozwój wanny 1200 S posłużył jako przykład pokazujący możliwości systemu, w którym różne etapy rozwoju mogą być wykonane równolegle.

1. Introduction

Collaborative design is a new concept for sharing design information and knowledge in various divisions in order to improve product quality and to reduce design time. In a collaborative system, designers and engineers can share their work with globally distributed colleagues via the networks. Huang at al. [1] developed a web based framework for concurrent product development. The framework integrated the concept of agents into workflow management. Frank et al. [2] constructed a data oriented concurrent engineering framework synchronizing the status of data. System offers customizable group management and the collaboration approach is characterized by the coordination of synchronous work on a common information space. Tang [3] constructed a collaborative design environment to facilitate active die maker involvement in metal stamping product development. The author takes the view that die maker should be involved in new product development processes as early as possible to enable concurrent engineering practice in metal stamping development.

Moreover, an integrated CAD/CAM/CAE system can tremendously improve productivity. Lin [4] took advantage of the concurrent engineering concept and developed an integrated CAD/CAM/CAE system for designing stamping dies of mobile phone. In most cases, the stamping product design is always separated from the die and process design, with the latter two being carried out by skillful die and tool

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makers using and experience-based and trial and error procedure. The stamping product and die development activities have been performed separately and sequentially by designers and engineers, as shown in Figure 1.

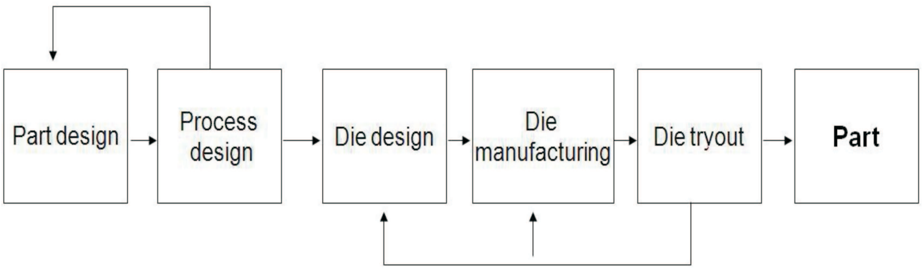

Fig. 1. A traditional process of part development (sequential engineering)

In recent years, the concept of concurrent engineering (CE) has been proposed to overcome the problems of the sequential design approach. In the practice of concurrent engineering, product, process and all life cycle issues are considered and reviewed throughout all phases of the development cycle. A concurrent methods for developing new products would depend strongly on how CAD/CAM/CAE system is applied to the design and analysis of the process, the tools and the part. Process using a integrated CAD/CAM/CAE approach with FEM simulation is shown in Figure 2. The data flow of developing a sheet metal part with FEM simulation is shown in Figure 3. With the help of FEM simulation, amendment of the preliminary or final design of the product die after the tool try-out can be avoided. Others forming parameters, which would result in a product with the required quality, can be determined in an efficient way [5].

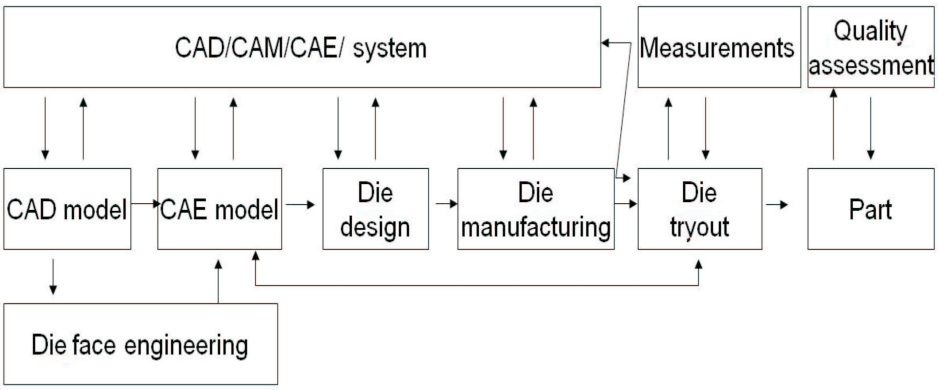

Fig. 2. A product development process with CAD/CAM/CAE system support

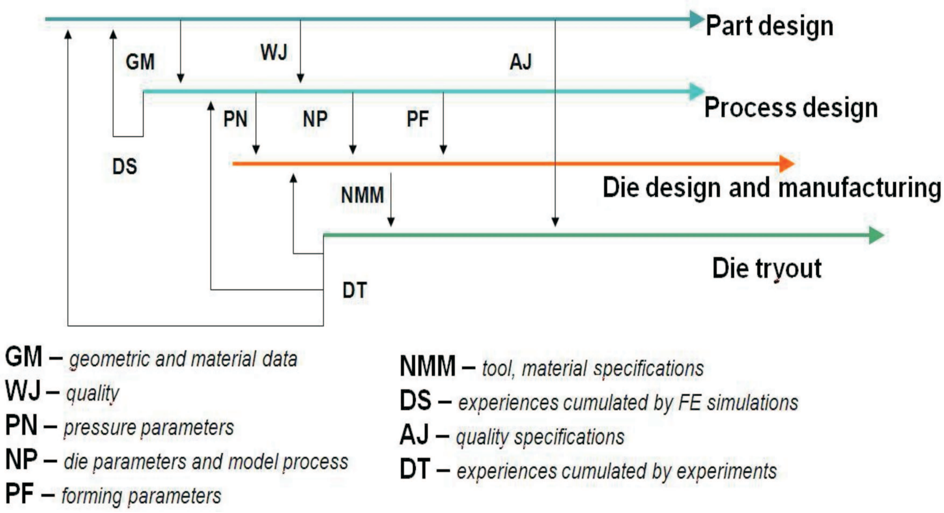

Fig. 3. The data flow in concurrent product development

This paper presents an integrated CAD/CAM/CAE/IBC system for redesigning stamping die of a bathtub 1200 S using concurrent engineering (CE). The redesign and verification of die for the stamping of bathtub 1200 was performed using finite element method. 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. The first set of die was performed without support of CAE/IBC system. The difficulty encountered in the real stamping process is the occurrence of both fracture and wrinkling, as shown in Figure 4.

Fig. 4. The split and wrinkles localization after stamping process of bathtub 1200 S

The stamped bathtub is made of DC06 grade steel 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 ±40%, respectively, required by the part design. The efforts focused on the die design for the stamping of a bathtub are mainly to avoid major defects such as wrinkling and fracture. A successful die design 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.

2. The integrated CAD/CAM/CAE/IBC system

The general scheme of the integrated CAD/CAM/CAE/IBC system for stamping dies is presented in Figure 5. This system includes a set of CAD die face design software, a set of stamping formability analyzing software, CAM software and product database. In this paper, an Internet-Based Collaboration (IBC) system has been developed to support and share design models and analysis results between geographically dispersed users. The system infrastructure and its mechanism are built based on some JAVA/PHP, Web technologies and Tomcat Web server. This system consists of two primary modules:
– a resource sharing module: FEM analysis results,
– a Web-based visualization module to support product preview of design parts.

In order to manipulate interactive 3D models effectively in the Web, some concise 3D formats for Web application such as VRML,X3D and MPEG, have been launched to represent the geometry of 3D CAD models. Most of the newest CAD systems are equipped with an export function to convert a native model to a concise 3D model for Web application (e.g. X3D or VRML).

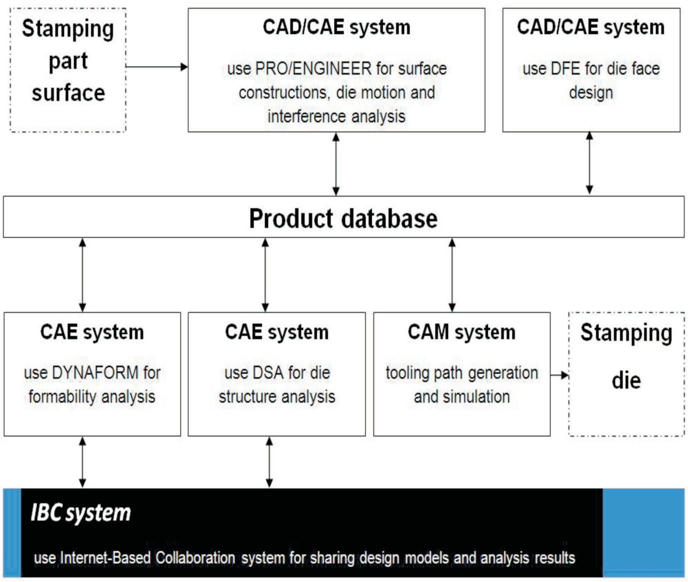

Fig. 5. The scheme of the integrated CAD/CAM/CAE/IBC system of stamping part

By using PRO/ENGINEER, DYNAFORM,DSA, IBC system and various product databases, an integrated CAD/CAM/CAE/IBC system was developed. Since the entire development process shares the same 3D model, the various process of developing die can be performed simultaneously, which can greatly reduce the development time.

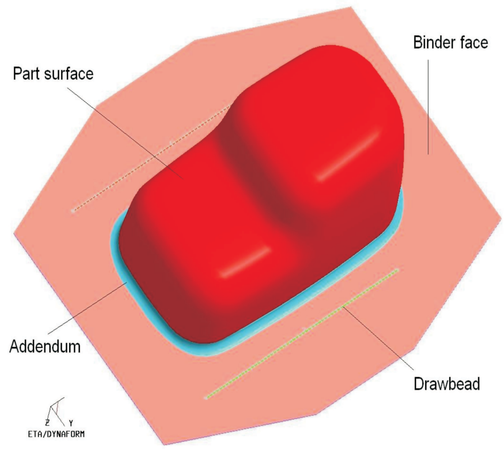

Fig. 6. Die face of a bathtub 1200 S

3. The application of an integrated CAD/CAM/CAE/IBC system

3.1. Drawing and trimming die design

Die face design is very important in the initial design stage. Die face design involves importing bathtub surface into DYNAFORM software using IGES format files, then the die face can be developed based on stamping design knowledge. FEM model of a die were prepared by using DFE (Die Face Engineering) module of DYNAFORM software.

By integrating with forming simulation, DFE helps to reduce iteration time for tooling design in the CAD system. Die face design includes addendum design, binder face design and drawbead design, as shown in Figure 6. Addendum is designed to assists forming and improve formability. Binder face is used to hold blank to avoid wrinkle before feeding into drawing cavities. Drawbeads are used to control blank to be evenly fed into drawing cavities to avoid any defects through changing its locations, lengths and cross section. Die used in this paper include drawing dies and trimming dies. A 3D solid model, which is identical to real product, is used in die design to avoid any interference and to facilitate design and modification, which fundamentally reduces the design time. Figure 7 shows a 3D solid design model of the drawing die. Drawing dies are used to shape the part. In order to obtain the desired shape, we need very strong forming force, which makes it necessary to evaluate its structural stresses. The structure of drawing dies includes e.g. drawing punch and cavity, guiding plane, blank positioning unit for upper and lower die set and blank holder. The assembly of the standard parts for drawing dies include e.g. screws, guide plates.

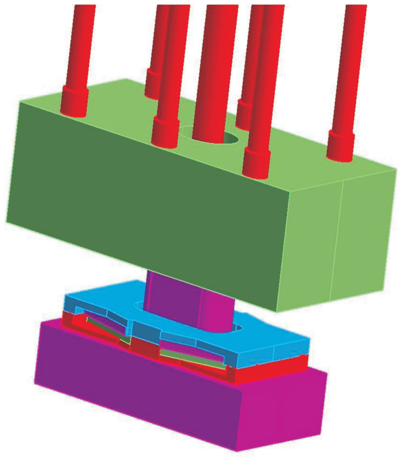

Fig. 7. 3D solid model of drawing die

Trimming dies are used to cut blanks. Since scraps will not be removed automatically, we need to add additional scrap cutters where necessary. Using analytical module (SSR – Scrap Shedding and Removal Analysis) built in DYNAFORM and LS-DYNA solver, we can analyze all trim process before completing die design to avoid extended down time due to scrap shedding and removal related issues.

3.2. Formability analysis vs. industrial die try-out

Blank material is DC06EK. Forming parameters and material properties need to be specified, which include thickness (1.5 mm), yield strength (144 MPa), hardening exp. n-value (0.243), and anisotropy r-value (2.19). The other process parameters, such as the friction coefficient and blank holder pressure, was set differently for the different stamping conditions. The strain distribution for various stamping conditions were established for designing an optimum set of stamping dies. The die design obtained from the finite element analysis was validated by the production part. The final part geometries generated by a PRO/ENGINEER system for the initial die design were provided by the CAD engineer. In the finite element simulation, the tooling is considered to be rigid. The contact conditions' proceeding during stamping of bathtub was identified by algorithms coded in DYNAFORM system. In the present work, the four node shell element was used to construct the meshes. An optimum sheet blank shape determined by the finite element analysis was used for all die designs by using BSE (Blank Size Estimated) module of DYNAFORM software. The four corners of this optimum sheet blank were cut off to facilitate metal flow at the edges. The shape of die cavity confirming to the geometry of the bathtub was also maintained, as for all of the die face designs, since the bathtub was drawn to the desired shape in one operation. In consequence, the die design was focused only on the die face. In order to analyze the metal flow, a flat surface without a drawbead was used as the initial design for the die face. The analysis of the modified die design was performed according to the pattern of metal flow obtained from the finite element simulations. In addition to the die face design, 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.

The clamping force of 1.6 MN exerted by the blank holder and the friction coefficient of 0.125 were assumed for the initial die design. The final shape that results from current design is shown in Figure 8. It can observe that some tendency of wrinkles appears on the draw wall. The major and minor strain distributions as well as the forming limit diagram are shown in Figure 9.

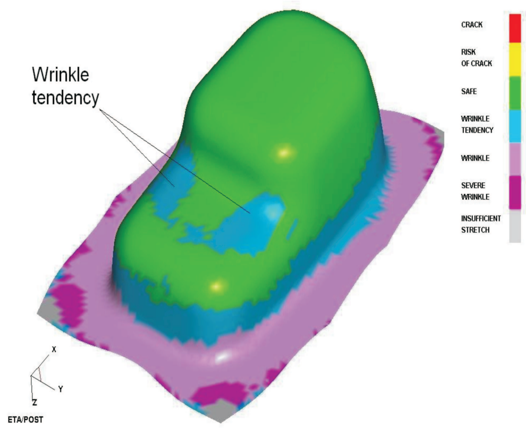

Fig. 8. Final shape of a bathtub 1200 S for the initial die design

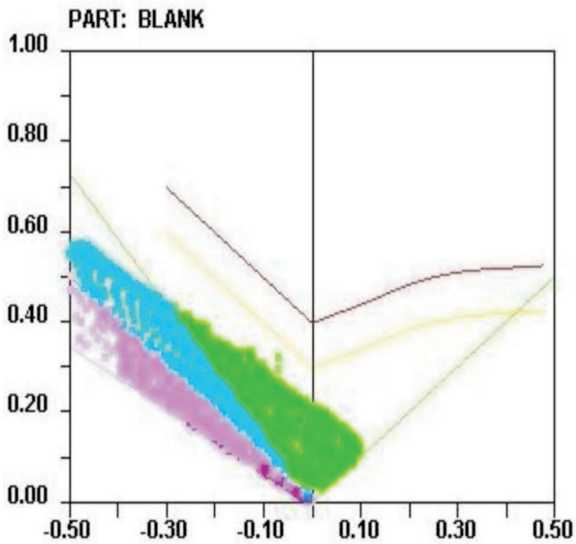

Fig. 9. The minor and major strain and Forming Limit Diagram (FLD) for the initial die design

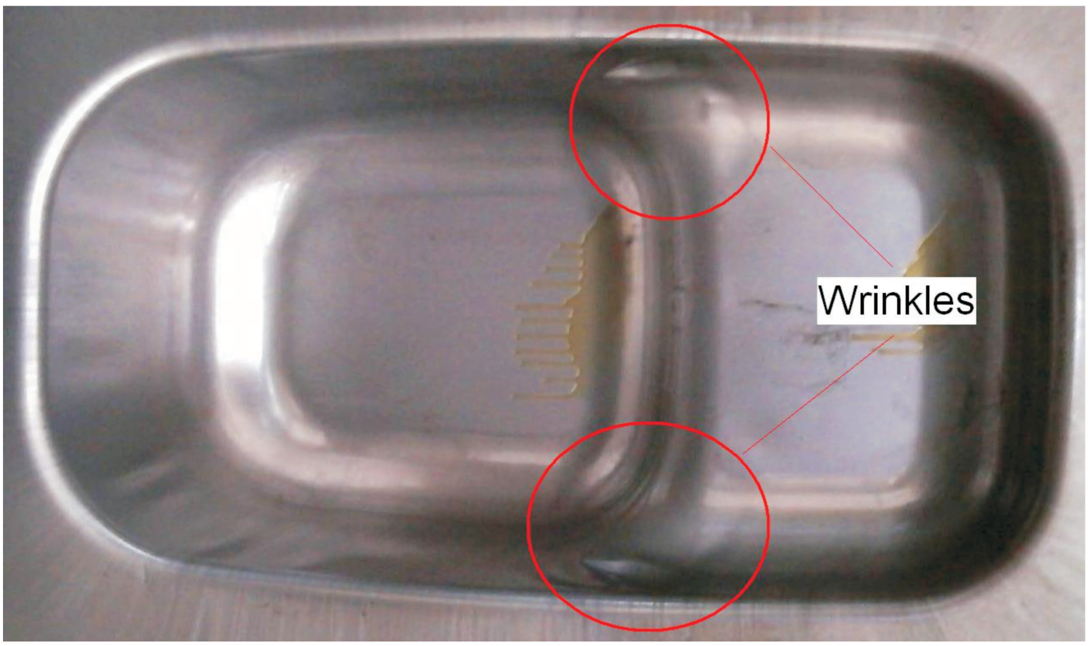

Fig. 10. The wrinkles localization after stamping process of bathtub 1200 S for the initial die design

As predicted by the finite element analysis, the production part is free from defects, however, in the present case, the formation of wrinkles was observed on the wall of the stamping bathtub, as shown in Figure 10. The wrinkles are not allowed in the final product so that the die face must therefore be modified. The formation of wrinkles resulted from a significant metal flow at these areas. One of the efficient methods of restraining metal flow in stamping die design is to add drawbeads on the die face. However, the determination of the geometry and location of the drawbead requires the analysis of metal flow during the drawing operation.

The wrinkles have disappeared when the blank holder pressure is increased from 1.6 MN to 4.0 MN, according to the simulation results (Figure 11). However, the major and minor strain distributions plotted on the forming limit diagram, as shown in Figure 12, indicate that the sheet metal is close to fracture since many of the points are above the risk of crack line.

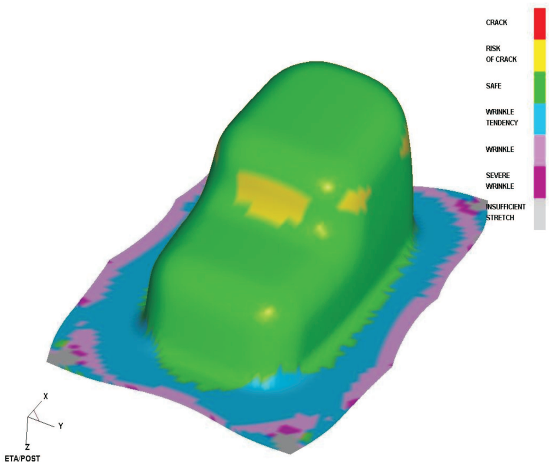

Fig. 11. Final shape of a bathtub 1200 S (blank holder pressure 4.0 MN)

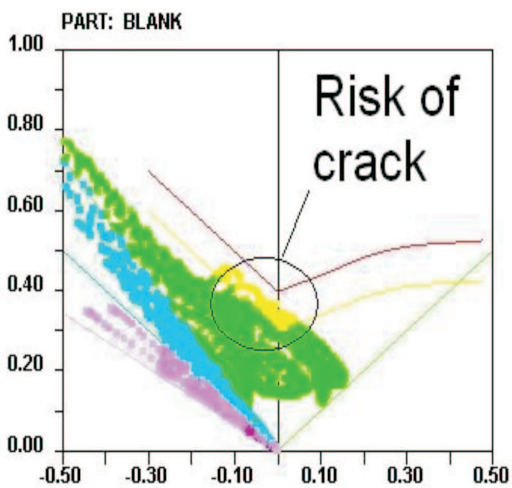

Fig. 12. The minor and major strain and Forming Limit Diagram (FLD) (blank holder pressure 4.0 MN)

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 0.125 to 0.28. Hence, neither of these methods yields a sound product and the addition of drawbeads on the die surface needs to be studied.

In the finite element simulations, the sheet metal that is pulled through the drawbead during drawing must be modeled by very small elements to reflect the effect of the bending deformation of the sheet metal around the drawbead, resulting in a large computation time (Figure 13).

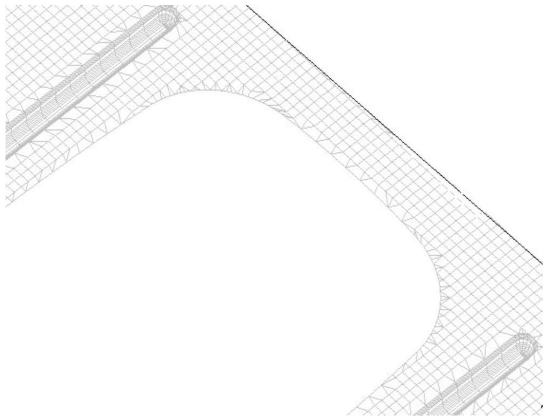

Fig. 13. The geometrical FEM drawbead model

In order to eliminate this problem, an equivalent drawbead model, was adopted to replace the full scale physical modeling of the drawbead in the finite element simulations [6-9]. When the equivalent drawbead model is used, large elements for the sheet metal passing through the drawbead can be assigned and in consequence, a huge saving of computation time can be achieved. In the equivalent drawbead model, the actual drawbead is replaced by its projection onto binder surface (Figure 14). The restraining force exerted by the actual drawbead is assigned 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. When the punch draws the sheet metal into the die cavity after the blank holder closure, the sheet metal passing through the drawbead is subjected to bending and subsequent unbending around the entry groove shoulder and a repeated sequence at the bead and the exit groove shoulder, as shown in Figure 14.

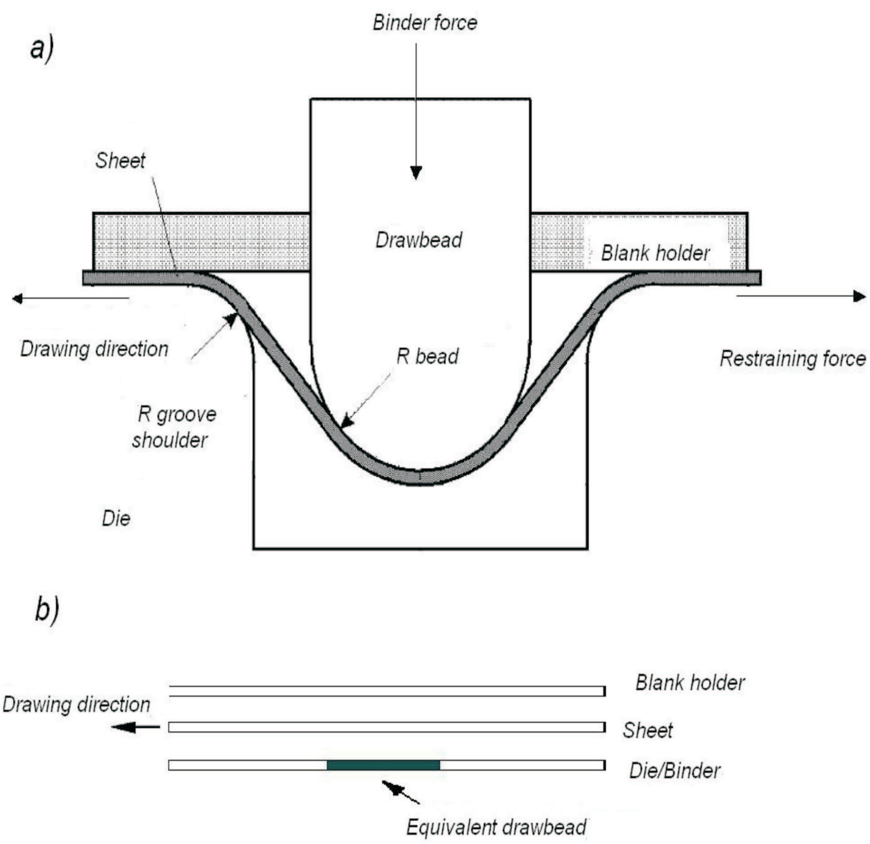

Fig. 14. Drawbead models: (a) geometrical, (b) equivalent

These bending and unbending deformations together with the frictional force account for the drawbead restraining force. Hence, the sheet metal passing through the equivalent drawbead model is subjected to the same restraining force as that exerted by actual drawbead. The restraining force produced by equivalent drawbead can be obtained by the finite element simulations, so that the FEM system can be used to estimate the total force exerted by drawbeads having different lengths [6-9].

In order to eliminate the wrinkles without causing the problem of fracture, the size and the location of drawbeads were designed. Following the observation of the metal flow obtained from the finite element results, the four drawbeads were used, as shown in Figure 15, denoted db1,db2 and db3,db4.

In the finite element simulation, the equivalent drawbead model was used and the restraining force produced by the actual drawbead was assumed, instead of considering the actual geometry of the drawbead. The designed shape of the drawbead can then be derived from the optimum restraining force that drawbead will produce. The drawbead lengths and the restraining forces produced by the drawbeads were modified repeatedly according to the

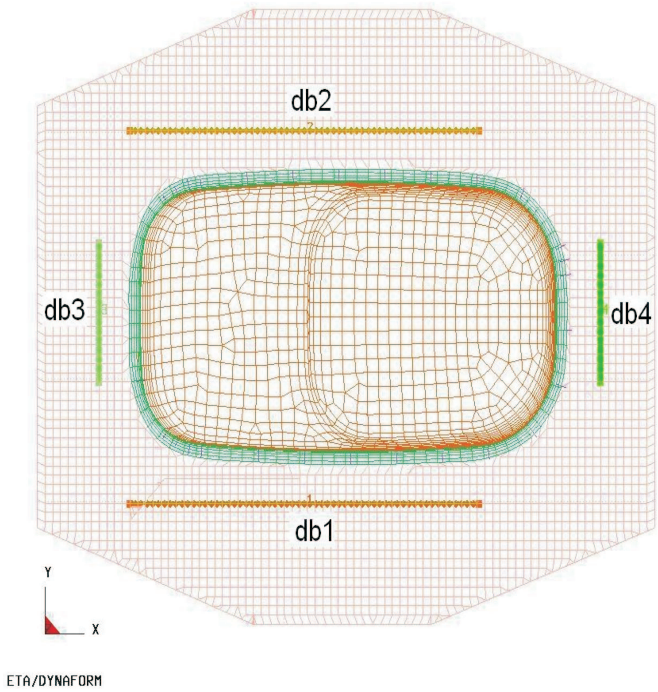

Fig. 15. Drawbead distribution on the die face

analysis of metal flow obtained from the finite element simulations until an optimum combination was achieved. The determined lengths for db1,db2 and db3,db4 are 900 mm and 300 mm, respectively. The restraining forces for all drawbeads are 95.140 N/mm. The restraining force produced by the drawbead is a function of the material properties of the sheet metal, the shape of the drawbead and the friction at the interface between the bead and the sheet metal [6-9]. The typical drawbead, in which the drawbead shape can be characterized by the radius of the bead (or the groove shoulder), as shown in Figure 16, was adopted.

The relationship between the geometry of the drawbead and the corresponding restraining force was established by the finite element simulations. The approximate drawbead radius for the corresponding restraining force was confirmed by the computer simulation. The drawbead radius (R1=R2) for the restraining forces of 95.140 N/mm, obtained from finite element simulations, is 6 mm. The exit and entrance radius (R3 = R4) of drawbead groove, is 24 mm. The drawbead width and height (W1 and H1) are 12 mm and 15 mm, respectively. The clearance of drawbead groove is 0.1 mm. The shape obtained from the finite element simulation with the use of the optimum drawbead geometry is shown in Figure 18, from which it is seen clearly that the tendency of wrinkles disappear and that the calculated flange width is greater than 70 mm (Figure 17). Thinning distributions results in – 12% and 27%, respectively. The thinning distributions range of 40% was contained. 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, such as the sheet blank shape, the blank holder pressure, the coefficient of friction and the drawbead locations, obtained from the finite element analysis.

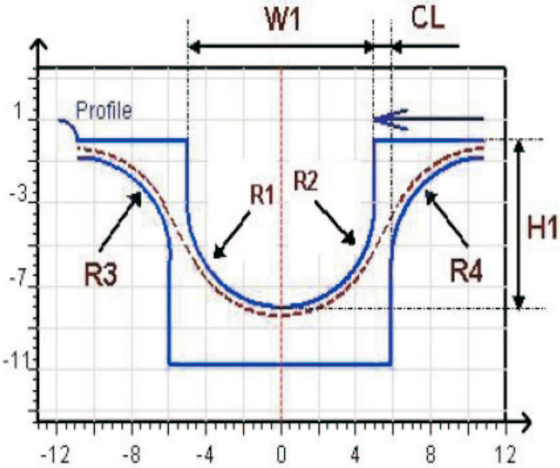

Fig. 16. Hemicycle drawbead profile

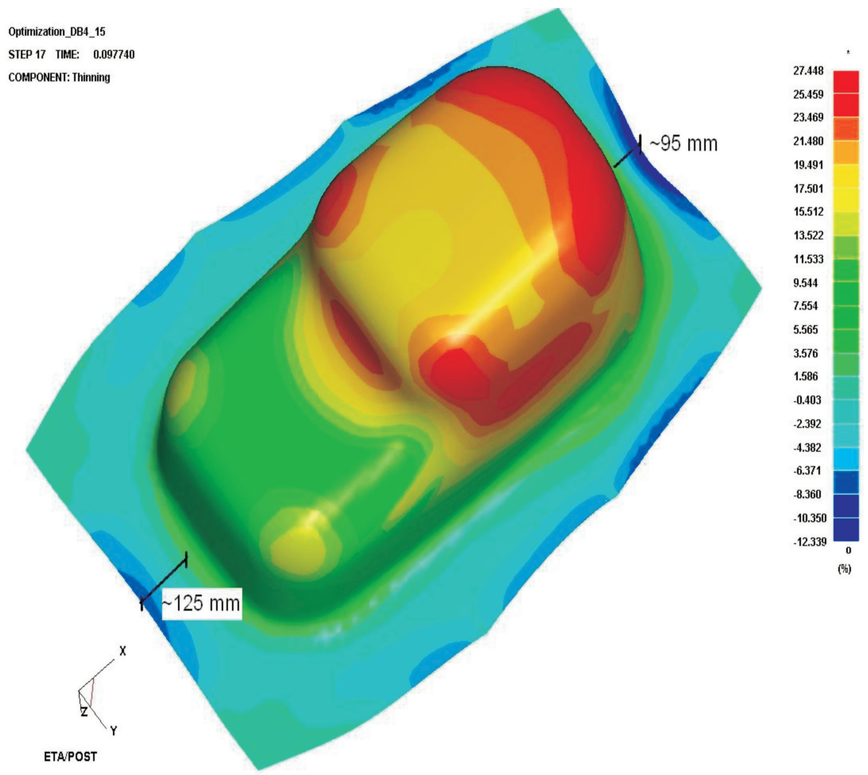

Fig. 17. Thinning distribution for the final part

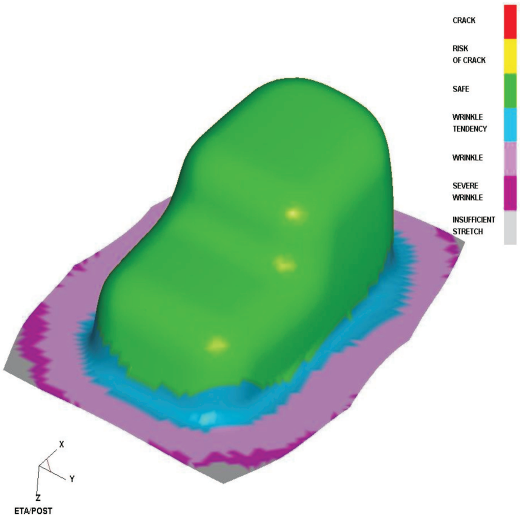

Fig. 18. Final shape of a bathtub 1200 for the modified die design

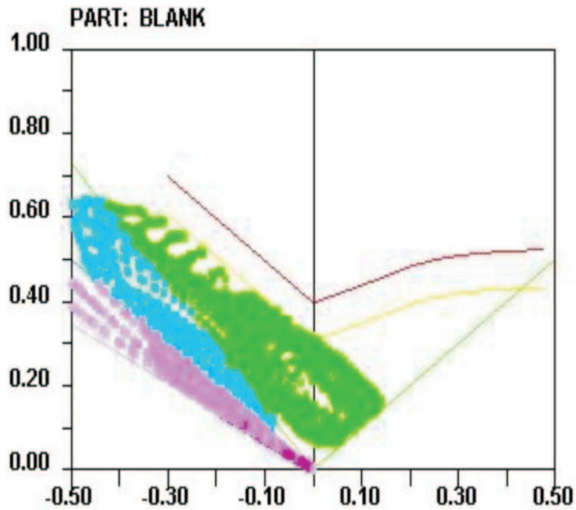

Fig. 19. The minor and major strain and Forming Limit Diagram for the modified die design

Fig. 20. The example photo of bathtub 1200 S before trimming operation

As predicted by the finite element analysis, the production part is free from defects, as shown in Figure 20. The actual part shape also agrees very well with that obtained by the finite element simulation. The defect free product confirms the advantage of using FEM system for stamping die design.

3.3. Die System Analysis (DSA)-Simulation Solution for Die System

Die Structural Analysis (DSA), is one of the important applications of stamping CAE. It enables the stamping CAE engineers to validate the die design changes and quantify the safety factors of die structures. Furthermore, the DSA is used to optimize

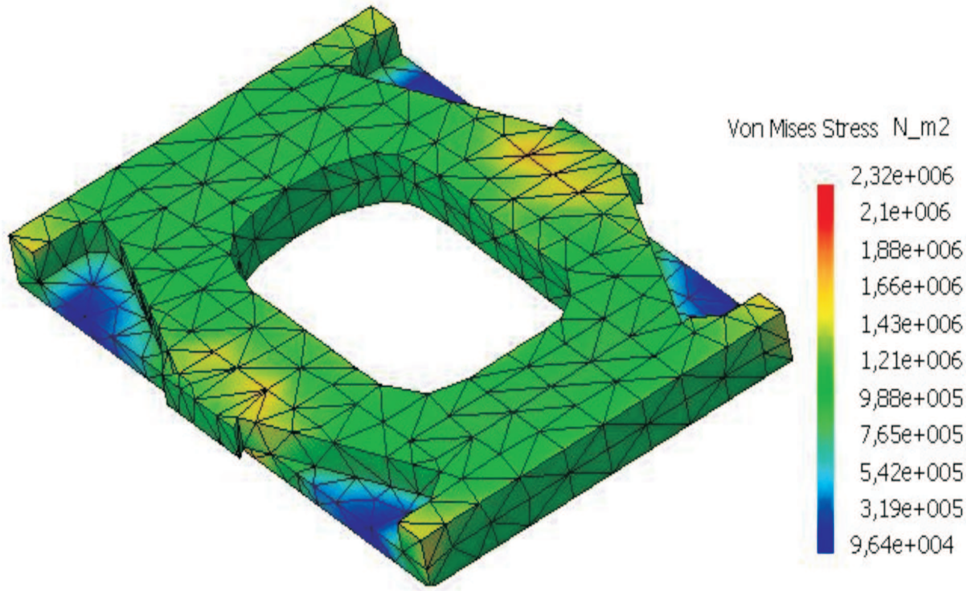

Fig. 21. Equivalent stress distribution for the low ring of the drawing die

the die design for weight reduction, hence providing opportunity for cost savings. The DSA is also utilized to identify root cause of die breakage during the tryout and stamping production. The benefits of DSA have provided significant values to the stamping manufacturers in terms of die construction and stamping operations. DSA Consists of three Sub-Systems: Die Structure Integrity (DSI), Scrap Shedding and Removal (SSR) and Sheet Metal Transfer and Handling (SMTH). The die structure shall have sufficient strength, and no interference is allowed among the various components. After the solid models have been developed (Figure 7), designers use the PRO/ENGINEER digital mockup module to perform motion and interference analysis on the models. After performing this analysis, any potential interference can be avoided and identified. In addition, since the stamping force is very large, it is necessary to perform a structural analysis on the models. In structural analysis, engineers apply forming forces obtained from the formability analysis and the die's boundary conditions to determine the stress. Figure 21 presents the stress distribution for the low ring of the drawing die. The evaluation criterion of the structure analysis is that the stress of the die must be less than yield strength of the die material divided by the safety factor.

4. Conclusion

This paper presents an integrated CAD/CAM/CAE system for stamping die development of a bathtub 1200 S using a concurrent engineering approach. In order to allow three geographically dispersed teams to simultaneously work on the development of products, the Internet-Based Collaboration (IBC) system has been developed. The IBC system enables users to share design models, analysis results and can notify design modification to users when it is required. Engineers can exchange information about common design maters by the conferencing function of the system and the annotation function. Using presented an integrated CAD/CAM/CAE/IBC system, the die face design for stamping of a bathtub 1200 S was investigated. In the investigation, the cause of the formation of wrinkles 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. In addition, an equivalent drawbead model was applied to the finite simulation to save computation time. With the use of equivalent drawbeads, the actual drawbead shapes are not considered until the optimum restraining force and die design is achieved, resulting in an efficient approach for drawbead application. At the end the industrial die verification has been done, where the defect free product has been obtained. With the aid of FEM simulation, forming problems can be visually identified and die tryout has been shortened into several days.

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