Incremental sheet forming applications

Freeform sheets are often used in the manufacturing industry, although their production is often expensive and labor-intensive, especially for short production tracks and prototypes. ISF (incremental sheet molding) offers sheet metal processing companies huge potential to achieve cost-effective short production runs of sheet metal-shaped 3D elementsTechnological technologies can be used to complement existing technologies or to produce specific components of sheet metal with freely formed product characteristics that are difficult or economically viable using traditional methods. Technology By combining ISF with other processes of working with sheet metal with its specific advantages, it is possible to achieve a further reduction in production costs. This in turn should lead to greater freedom of design and therefore to new products and applications. There are three different methods, depending on how the blank sheet is maintained: TPIF (two points of gradual molding) uses a complete or partial matrix to support the workpiece during formation; The most well known and widely used is SPIF (single-member gradual molding), where no matrix is used and the sheet is kept in a bracket, usually in combination with a pad; KISF (kinematic gradual molding of a sheet) is a variation that uses two pins, one of which acts as a grooming tool, and the second pin gives local support on the other side of the sheet. ApplicationsStyle of possible applications can be found in a whole range of different areas: architectural 3D structural components of external walls for modern buildings and structures;all types of products for the automotive industry, such as bodywork prototypes, individualized components for the upper part of vehicles, from sheet metal, components or shapes for plastic or composite components for aircraft, aerospace, sanitary accessories , etc. , components for wind turbines;storage tanks for foodstuffs, liquids and gases; Patient-specific orthosis and implants Application lab In collaboration with KU Leuven, Sirris created an application laboratory, thus ensuring that all existing knowledge and experience are transferred to the industry. The lab also gives the industry access to infrastructure, knowledge and technological support, as well as enabling research and testing of the technology for itself. The gradual formation of a sheet (FSF) was created as a flexible formation process in the 1990s. The basic principle of FSF is that a generic beaded tool moves along the path of the instrument and gradually forms a metal sheet in the desired shape. The tool is moved either using CNC machines or industrial robots. The application of CNC technology or robots for molding sheet metal allows special tools and to quickly transfer from the CAD model to the formed part. Since its first application in the 1990s, it has undergone huge changes. Various versions of the process, such as bilateral bilateral and hybrid combinations of processes, such as heat-assisted FFFs, as well as for the formation of the plot and the FSF. This contribution provides an overview of these developments, paying particular attention to the results of the research achieved within the Cluster of

Excellence Integrative Production Technology for high-paying countries, where the development of fully integrated sheet metal production facilities is envisaged as the next step in the development of the ISF. The development of specialized equipment for the production of hybrid and fully sheet metal and specialized CAX environments, as well as applications to demonstrate the potential of the technology. Sheet Metal Tool Tool Path Hybrid Process Shape Border Curve Angle Wall These keywords are added by a machine rather than the authors. This process is experimental and keywords can be updated as the learning algorithm improves. Download conference PDFIframental sheet molding (ISF) is a flexible molding process for small batch production and fast prototyping of almost arbitrary 3D shapes. In ISF, the clamping sheet is gradually formed by a moving beaded tool (Fig. 9.1, right). Unlike conventional sheet metal molding processes such as deep pull (Fig. 9.1, left), only one meticulous punch is needed, which should not be full male or female punching, but can be partial support.Fig. 10. , similar to the final phase in z-level processing. At every moment of the formation process, in which the tool moves on sheet metal, localized plastic deformation is produced, and the final part form is the result of all localized plastic deformation events. In the past, several variants of the process of gradual leaf formation were developed: Conventional FF. Conventional PE includes the variants of single-member gradual molding (SPIF) and gradual formation of two points (TPIF). In SPIF either there is no support, or only a simple platform is used to maintain the outer contour of the part. In TW, the sheet metal is formed on a complete or partial positive matrix. Two-sided ISF. In this variant of the process, a tool is used on both sides of the sheet, with one tool acting as a tool for shaping the master, and the other acting as local support. This process is being investigated by Meier et al. (2007), Maidagan et al. (2007) and Malhotra, etc. Stretching and FSF. In order to overcome some of the limitations of conventional variants of ISF processes such as long process times, pronounced thinning and limited geometric accuracy, FTT is combined with stretching formation to hybrid process by Taleb Araghi et al. (2009). The process is carried out on a special machine that combines four stretchable aggregates and a CNC unit for ISF. Heat-aspiring FSF. In order, for example, to form titanium or magnesium alloys with low variants of PE supported by heat have been developed, such as using a laser isff from Duflou et al. (2007) and Göttmann et al. (2011), or a heating resistance ISF, see, for example, Göttmann et al. These variants are also hybrid processes, the adjustment and control of which is much more engaged than for conventional MF. Both conventional FTT and newer process variants have been developed with great effort by a number of research groups, but so far only with limited industrial access. The main limitations of conventional FTT are (i) limited geometric accuracy, (ii) excessive thinning of leaves, (iii) the long process time and (iv) the need for special CAE tools. Moreover, potential markets for FTT are parts of sheet metal made of titanium and magnesium alloys that are difficult to form at room temperature and require formation at elevated temperature. In order to meet the above challenges and make the FSE viable in an industrial context, various technological developments outside the conventional MF are needed. This contribution provides an overview of the latest developments in the FTF with a strong focus on the hybrid processes of the FF developed in the Cluster of Excellence integrative production technology for high-wage countries. The paper is organized as follows: The following section provides an overview of the design of the special machine for hybrid ISF processes and the CAX tools needed to work with the machine. The capabilities of hybrid stretching processes and FSF, as well as of the FSS with the help of lasers are shown with the help of case studies. Finally, the advantages of hybrid processes compared to the standard FVF are summarised. The machine, shown in Fig. 3. Thus, the stages of the process of milling the matrix, stretching, FF and trimming can be carried out on one machine.Fig. 12. 9.2 (left) Hybrid machine that allows stretching formation and ISF. (Right) machine bed bending simulation Especially remarkable is the rigid bed machine (Fig. 9.2, right), which must carry the extremely high technological forces exerted by the formation of stretching (about 200 kN per element) in a confined space. In addition, an interface has been created in the 5-axis head, which can receive molding tools for FTS, as well as conventional milling tools. For ISF, a force limiter has been developed to protect the linear and rotating axles of the milling machine from overload. For both stretch molding and ISF, a blank holder is required to transmit high-tech powers. Modules forming stretching allow movements in a horizontal and vertical direction and have a hinge. This is necessary to allow for tangent stretching. The tightening of the parts is self-adjusting and is designed for sheet metal with a thickness of 1–4 mm. All movements are performed by NC controlled linear axes. During grinding of the can be used as a 5-axis milling machine with three linear axes and two rotary axes. With the system can be used commonly used mold materials for ISF (aluminum, plastic, wood). The machine is equipped with CNC control Siemens 840 D NCU 573 SL. Thanks to the flexible architecture of the controller, it is possible to integrate special control functions for stretching the molding and entangling sheet forming directly into the controller. This functionality has been used to integrate a laser system as a further axis (see below). The technical data of the installed system are summarized in Table 9.1.Table 9.1 Technical data of the hybrid stretching machine and ISF In order to allow localized heating, laser optics are also designed in the machine. The selected laser is a diode laser LDF 10000 from the company Laser Line. The maximum available power of 10 kW (radiation power) is sufficient to heat ordinary sheet formation materials to temperatures above 1000 °C. The main advantages of the diode laser are that the beam can be controlled by optical fiber. Thus, the necessary energy for heating can be directed directly to the formation area. The movements of the molding tool can be compensated by optical fibers and a power supply. Since the optical system cannot revolve around the instrument, it is designed so that the laser beam rotates to the desired position around the axis of the instrument. The rotation of mirrors in laser optics causes the laser beam to move in a circle. The shape and position of the laser spot can be influenced by selecting different lenses and changing the distances between the components of the mirror. In the simplest version, a round laser point with a diameter of 35 mm is projected on to the surface of the part at a distance of 45 mm from the axis of the instrument. The optical system described is fixed to the forming head of the hybrid machine (Fig. 9.3). The source of the beam is outside the machine, so the laser beam must be directed to the processing point by optical optical. The optical system moves together with the processing head during the formation process. The laser spot is positioned with a motor that is built into the optical system.Fig. 9.3 Hybrid molding machine with built-in optical system Medium CAX must provide appropriate software tools for planning every step of the combined stretchform and ISF process circuit, as well as for laser-assisted ISF. Due to the complexity of the kinematics of the ISF tool clean manual operation machine would not be possible. The same detentions for stretching, forming up to 8 axes. Due to the novelty of the combination of the stretching process and ISF, the development of new CAM features is necessary that do not exist as standard characteristics in common CAX systems. The programming of the plot formation operation is supported by the CAM system, but it is also possible to manually control the modules forming a section and trajectories back into the CAM system. Previously used PE PE strategies customized and expanded. Checking the simulation and collision of the molding tool, the movement of the machine and the situation with the devices are another important requirement. Developing a completely new and independent CAX solution will cost a tremendous effort. For this reason, the development of the CAX solution takes place on the basis of the standardized CAX platform NX by Siemens. A key criterion for selecting NX as a CAD/CAM platform is the ability to integrate its own functions into the system through programming interfaces and thus perform specific stretching functions and ISF. NX offers several programming interfaces (APIs) such as NXopen (C, C++, Visual Basic). The CAM module in NX provides basic milling functions that can be adapted for 6. The most important function is processing at level Z. This processing strategy can be programmed with NX in both 3-axis and simultaneous 5-axis movement. All steps of the process for the production of demonstration components – geometry processing, stretching, ISF and component trimming – can be performed sequentially with the developed CAX-chain. Pre-stretching the sheet, approaching the matrix and bending can be combined within a smooth trajectory. Since the modules forming stretching move in planes, movement can be prescribed by curves in 2D space. They can be determined separately for each section molding module. For the individual formation steps can be determined the corresponding parameters in the form of input values (Fig. 1). 9.4.Fig. 9.4 Programming the plot drawing (left) and graphical representation of machine kinemathetics (right) Since stretch molding does not create the final geometry for most parts, the areas that still need to be formed by ISF after stretching the shape must be detected. This is achieved by taking into account the results of a simulation of the final element of the plot formation process in the CAD/CAM system. The areas to be shaped by the ISF are detected and the planning of the tool's path is carried out only for the areas shown in red in Fig. 1. In the case of the hybrid process, in addition to the five beading/cutting axes, eight more axles are available for the stretching devices. This underlines the need to simulate the system to ensure safe operation. The simulation avoids system test runs and therefore contributes significantly to shortening process planning. Special CAM tools for FFS with laser assistance are also needed. Special laser optical means have been developed to guide the laser beam on to a position on the blank, which is determined by the angle of rotation on the X axis (Fig. 9.6). The rotational angle is calculated in the CAM system and the molding machine together with the positioning signals of the formation tool.Fig. 9.6 Integration of the laser as axis of rotation (left) and integration into the machine via SPS (right) As part of the application is selected a reinforced frame for hydraulic input of an AIRBUS A320 aircraft made of stainless steel 1.4541 (Fig. 9.7). The part is located at the top of the pylon and allows easy and fast maintenance of hydraulic systems in this area. 9.7 (left) CAD drawing of the part. (right) Position of the part of the aircraft Usually, the part is produced using a technological chain consisting of separate manufacturing operations, i.e. shaping and trimming. Especially for small batch sizes, the cost of additional equipment and tooling increase the cost of a part. In order to develop an effective scenario for integrative production for small batches, the hybrid machine allows to perform all the steps of the process of one machine in one setting. In order to analyze the utility of the combination of processes, the part is produced both using conventional ISF and with the combination of ISF and stretch-molding. Both parts are trimmed to the final geometry using the milling functionality of the machine. In the case of pure FTT, the formation operation is divided into two steps. In the first stage, the outer envelope of the part is formed. Pockets are produced separately in the second step. The formation of SF + FF takes 60 minutes, while production with the conventional ISF process takes 110 minutes. With the help of the combination of the process, the formation time is reduced by about 45 %. Since the shape of the part shows a smooth curvature with relatively flat pockets, low strains are expected, which should not lead to significant thinning of the sheet, but affect geometric accuracy. Therefore, in the framework of this study, the accuracy of the dimensions was examined. Both parts (the clean FFF and SF + ISF part) are digitized using the gom ATOS system. The comparison of the digitized parts with the CAD model resulted in actual geometric deviations. Figure 9.8 shows the assessment of geometric deviation along a longitudinal section. After trimming, the clean ISF gives a lower accuracy of dimensions compared to the part made by the combination of the process. In particular, with regard to the boundaries of the part, the geometrical deviation of the section made by the FSB increases strongly. It can be concluded that for the combination of SF + ISF processes, the oversimposed tensile voltages due to stretching of the tension give a higher accuracy of dimensions in the area that is close to the outer limits of the part and in the transition to the flange than the pure PE. For stretching, spring compensation procedures by modifications to the tools can help increase the accuracy of dimensions even more.Fig. At room temperature, molding is very low due to the limited number of sliding systems. To analyze the from different process parameters such as temperature, voltage speed and load of TiAl6V4 deformation behavior, processing cards have been developed (Johnson et al. 2003). Vanderhasten et al. (2008) analyzed the deformative behavior of TiAl6V4 through a single-wax tensile test for a wide range of voltage and temperature levels. However, since the FFS is controlled by complex voltage states in the formation zone, the processing cards or single axial test data are not representative. In the cluster of excellence, the molding of TiAl6V4 sheets is analyzed by recording curves of limit values, both at room temperature and for slightly elevated temperatures of 300–500 °C. This is achieved by heating a blow to the corresponding forming temperature. The FLC in Figure 9.9 on the left shows that the forehand capability is already increasing in the temperature range of 300–500 °C.Fig. 9.9 (left) Formability of TiAl6V4 at room temperature and fever. (right) Forming a test form at room temperature and ~450 °C. Instrument wear and surface quality are shown at the bottom At such low temperatures, oxidation, i.e. the formation of harmful α-case, does not yet occur during laser ISF, since the time spent at this temperature is too short. Based on the molding analysis, experiments on sheet metal with a thickness of 1.5 mm Ti grade 2 and TiAl6V4 were carried out using local laser heating (Fig. 9.9, right). The formed geometry is a cone with a kidney with a 60° wall angle and a depth of 110 mm, as shown in Figure 9.8. The height between the z-levels is 0.35 mm. The formation rate is set to 4000 mm/min. The laser optics settings were selected so that an elliptical laser spot measuring 15 mm ×45 mm is projected on to the sheet metal at a distance of 45 mm to the instrument. The output power of the laser was controlled using a closed loop feedback controller. The temperature shall be measured at the top of the forming instrument 1 mm below the surface of the form-shaped instrument. Although the part is formed successfully, there is excessive wear of the tool and the surface quality is poor. The formation of TiAl6V4 using ISF requires improved tools, such as rolling tools, rather than a sliding contact. The most restrictive limitations of the process in conventional ISF are the geometric accuracy and the strong dependence of thinning of the sheet from the corner of the wall of the formed part. Allwood et al. (2005) considered 28 products from a potential sheet metal from 15 companies to search for potential applications of FSF. The product segmentation approach showed that only two out of 28 products met the capabilities of the FSF. In the study, geometric inaccuracy 3 mm is assumed to exist regardless of the size of the part and material of the workpiece. Although the assumptions made for the achievable toleration of the ISF in the products segmentation are super-simplified, they show that geometric tolerance is a key factor deciding whether a product can be produced by the ISF or not. Due to the possibility of preparation by stretching and due to the fact that tensile voltages can be oversimposed, the combination of stretch molding and FF helps to improve geometric accuracy, as shown in Fig. 3. This illustration assumes that the geometrical deviations in the ISF scale by the size of the part. The FSB increases the area of the part. Diluting the ISF process is guided by sinus law,$$ \text{t}_{1} = \text{t}_{0} \sin (90^\circ\upalpha) = \text t{_{0} \cos (\upalpha) $1 and increases with a wall angle. Thinning in stretching does not depend on the corner of the wall, it is rather friction-controlled restrictions. The combination of FFS and SF can help improve the limit of the process determined by excessive thinning. Assuming that the sheet breaks after reaching a certain amount of thinning, stretching formation should be ideally designed to result in homogeneous thinning throughout the part so that there is no weak spot with maximum dilution. , it can be complementary in many cases and therefore the reduction in thickness can be distributed more evenly over the part as shown in Fig. 3. Due to volume strength, leaf stretching should be compensated by thinning, i.e. $S_{0} t_{0} = S_{1} t_{1} $$ Fig. 9.11 Thinning in ISF and the combination of SF and ISF If the surface stretching ratio Ln(S 0/S 1) is distributed unevenly on the part, there will be an area of maximum stretching and therefore maximum thinning. This area is prone to failure. To avoid this, the material should be distributed as homogeneously as possible. The benefit of forming materials with a low degree of domo at room temperature such as titanium and magnesium alloys at high temperatures is shown in Figure 9.12.9.12 ISF process limits at room temperature and fever Again Provided that there is a maximum permissible thickness reduction, an increase in temperature will increase the limit strain from εmax,RT at room temperature to εmax,HT at high temperature deformation. This allows for a larger increase in the surface and therefore the formation of more complex parts. The authors would like to thank the German Research Foundation (DFG) for supporting depicted research within the Cluster of Excellence Integrative Production Technology for high-paying countries. Parts of this research are funded by the German Federal Ministry of Education and Research (BMBF) under the Framework Concept Research for Tomorrow's Production (funding number 02PU2104) managed by the Karlsruhe Project Management Agency (PTKA). 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