Review on the Development of a Hybrid Incremental Sheet Forming System for small batch sizes and individualized production

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Abstract:

Asymmetric Incremental Sheet Forming (AISF) has been developed as a flexible process for low-volume production of sheet metal parts. In AISF, a part is obtained as the sum of localized plastic deformations produced by a simple forming tool that moves under CNC control. In spite of about 20 years of research and development, AISF has not had much industrial take-up yet. The main reason for this is that attempts to improve, among other limitations, the accuracy, speed and range of feasible geometries of the process by adapted process strategies has not brought about general solutions. This paper presents an overview of the current state of development of hybrid asymmetric incremental sheet forming processes at RWTH Aachen University. The goal of the development of hybrid ISF processes is to allow for a quantum leap of the capabilities of AISF in order to enable a broader industrial use of AISF. Two hybrid process variations of AISF are presented: stretch forming combined with ISF and laser-assisted AISF. It is shown that the combination of stretch forming and AISF can improve the time per part, sheet thickness distribution and accuracy of the final part. Laser-assisted AISF is shown to enable the flexible forming of non cold-workable materials such as magnesium and titanium alloys when the forming conditions are adapted to the temperature and strain rate dependent formability of the sheet metal. In addition, first results of the forming of hybrid aluminum-steel sheet metal are shown.

Keywords: Production process, sheet metal forming, hybrid asymmetric incremental sheet forming, forming of multi-material

1 Introduction

The process principle of asymmetrical incremental sheet metal forming was first described by Mason in 1978. Mason recognized that flexible forming of sheet metal parts for small batches is possible using a “spherical roller” that can be moved along 3 axes. The principle of using a simple forming tool that moves along the contour of the desired part offers a number of advantages: tooling is reduced since only a single die is needed, the die can be made of cheap material since the forming forces are low, and part size is rather limited by the working space of the machine than by forming forces.
Since the 1990s, when CNC machines and industrial robots became broadly available, AISF has received considerable attention from researchers all over the world. Technological developments of dedicated forming machines, flexible tooling and fixture systems have been carried out along with theoretical analyses of the process mechanics.
As conventional AISF, two main variations of AISF are distinguished: ‘single point incremental forming’ (SPIF) and ‘two point incremental forming’ (TPIF) (see Fig.1). All process variants share the same forming concept: a metal sheet is clamped in a blank holder and formed by the movements of the forming tool. In TPIF, a partial or full male die can be used, whereas in SPIF, no support tool is used. This affects the dimensional accuracy but increases the flexibility of the SPIF process. For a more comprehensive overview of AISF, the reader is referred to the review provided in [1].

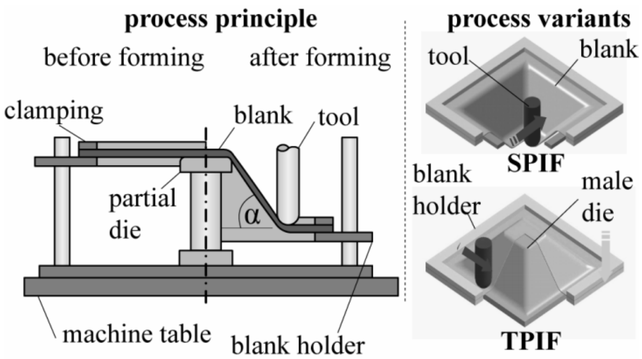


Fig.1: Process principle and variation.

Yet, AISF has not had much industrial take-up. There is a barrier between academic research and industrial application which is formed by physical process limits and limited knowledge and models for process planning:

Physical limits are a consequence of the process mechanics, i.e. the localized forming:

- localized stretching leads to localized sheet thinning which eventually causes failure when the forming limits are exceeded; considerable material flow from portions of the sheet metal that are outside the forming zone cannot be triggered by the localized deformation
- localized spring back occurs in AISF whenever the forming tool moves and creates localized elastic-plastic deformation
- Cyclic deformation builds up residual stresses which trigger springback after trimming and cause deviations from the target shape
- The process speed cannot be increased considerably since process time scales with the surface of the part and the tool pitch

As a consequence of the physical process limits, complex parts require dedicated forming strategies to reduce sheet thinning and to improve the accuracy of the part. However, there is no methodology or model based on which a suitable forming strategy can be defined. Process models based on finite element analyses are rather time-consuming due to the length of the process. Hence, production of parts is based on experience or trial-and-error optimization of the process which makes process planning too uncertain for many industrial applications.

Instead of making gradual improvements to AISF, it seems an interesting alternative to make up for the disadvantages of AISF by combining it with other forming processes and/or physical mechanisms. Within the Cluster of Excellence "Integrative Production Technology for High-Wage Countries", hybridization of manufacturing processes is analyzed as a means of achieving drastical increases in process performance. In this context, hybridization of asymmetric incremental sheet forming (HAISF) processes is analyzed to produce a quantum leap in process performance compared to standard AISF:

- The combination of AISF with stretch forming has been developed to reduce forming time springback and undesired or excessive sheet thinning.
- Laser –assisted AISF has been developed to allow for the manufacture of parts from non cold-workable materials such as titanium or magnesium alloys. This development is not motivated from limitations of AISF but from limitations of the material formability. Nevertheless, the production

of sheet metal parts from titanium and magnesium alloys with AISF would increase the range of possible applications of AISF, e.g. to aerospace parts.

- Another interesting development is the processing of hybrid materials, e.g. sandwich materials or hybrid combinations of different metals. Joined hybrid aluminum-steel sheets offer various advantages for lightweight applications but are different to form in processes that impose a global deformation. AISF with its localized plastic deformation represents a potential process that would allow for the production of hybrid aluminium-steel sheet metal parts.

The development of hybrid process variations and the forming hybrid materials of AISF requires cooperative work in the field of metal forming, material science, laser technology and joining.

The reminder of this paper gives an overview of these developments. First, a review of the state of the art in AISF will be carried out. The process combination of AISF with stretch forming and laser heat treatment as well as the forming of tailored hybrid blanks will be motivated and illustrated by some basic developments and results.

2 State of the art in AISF

In this chapter, the state of the art in AISF will be briefly summarized, including some approaches to overcoming the current process limits

2.1 Sheet Thinning

Sheet thinning in AISF can be estimated by the 'sine law', which describes sheet thinning as a function of initial sheet thickness (t_0) and the wall angle α (see Fig.1 for the definition of α) [1,2]:

$$t_1 = t_0 \sin(90° - \alpha) \quad (1)$$

As a consequence of sheet thinning, forming of parts with wall angles greater than 60-70 degrees generally leads to fracture. Thus, multistage forming strategies have been developed in order to avoid excessive thinning (see e.g. [3,4]). In multistage forming, a pre-form, several intermediate shapes, and the final geometry are formed by AISF. Hirt et al. [5] showed the production of a square box of 200 x 200 x 60 mm^3 in 15 forming stages as a case study, where a forming time of approximately 7 hours was required (see Fig. 2). In order to obtain a sound part without fracture and/or wrinkling, the intermediate stages had to be found by 'trial-and-error'. Hence, the multistage approach cannot be easily transferred to more complex parts.

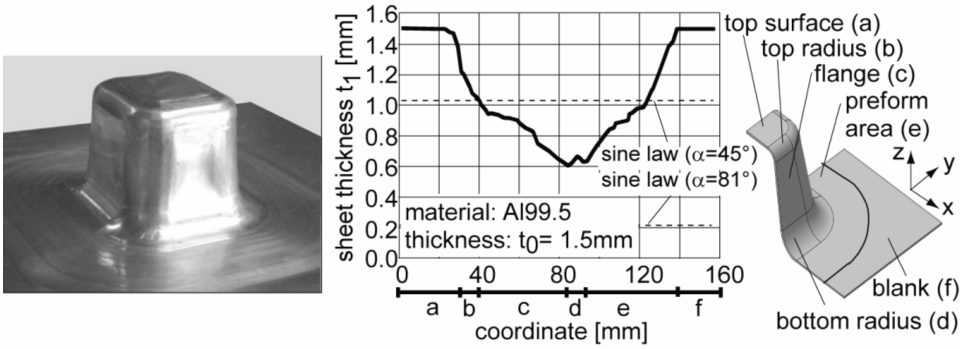


Fig. 2: Produced box by means of multistage forming (left), measured thickness profile after forming (right) [5].

2.2 Geometric accuracy

Parts formed by AISF show geometric deviation to the CAD-model in dependency of geometry size, used material and sheet thickness, and stiffness of the deformed geometry. In addition, the forming tool path strategy heavily affects the dimensional accuracy of AISF [6]. To improve the geometric accuracy, Taleb et. al. [7] proposed the application of multistage forming strategies combined with heat treatment as stress-relief annealing. In a case study, the authors investigated the dimensional accuracy of the part depicted in Fig. 3. The geometry processed by multistage forming and heat treatment shows up to 84 % less springback before trimming than the one produced by 'single-stage' AISF. After trimming the part, the geometric accuracy decreases considerably as result of springback. Multistage forming can make a contribution to reduce springback, but the optimal strategy has to be found by 'trial-and-error'.

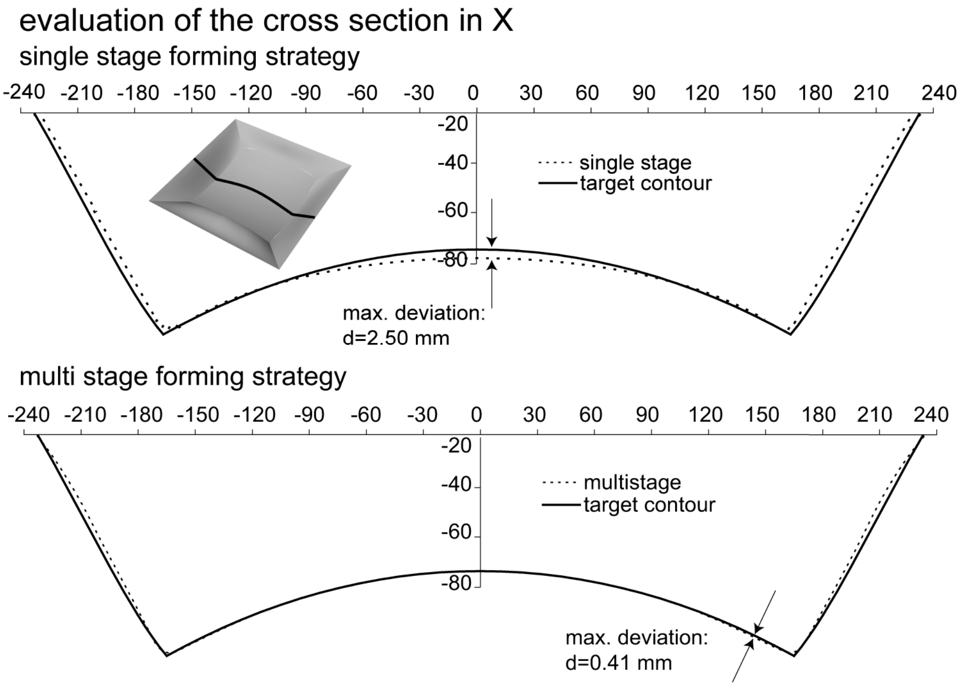


Fig. 3: Depiction from [7]. Evaluation of geometric deviations.

2.3 Process time

AISF is a kinematical forming process. The time to produce a part is defined by the part's size, and accordingly by the length of the tool path and the average feed rate of the tool. Bambach [8] showed that forming time is proportional to the surface area covered by the tool path and inversely proportional to tool pitch. The tooling concept is one of the few possible approaches to reducing the forming time in AISF. Kwiatkowski et al [9] introduced a new tooling concept ('twin tool") that adopts two forming tools in one machine set-up. In comparison to standard machines, the 'twin tool' halves the forming time. Nevertheless, only axis-symmetric parts can be produced using the 'twin tool' design.

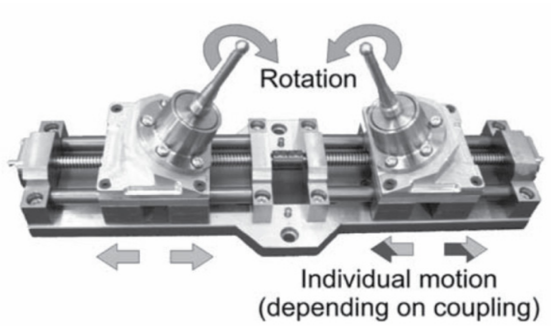


Fig. 4: tooling concept "twin tool" [9].

2.4 Finite element modeling

Since AISF is a kinematical forming process, CPU-times for finite element modeling are too large to allow for virtual try-outs. As reported in [8] the CPU-time can be in the range of days or weeks for larger parts. This makes FE-modeling prohibitive for larger parts. Some efforts have been made to speed up the FE-simulation of AISF. A possible approach is based on domain decomposition, where the sheet is divided into two regions. The first region is the forming zone and is treated by non-linear elastic-plastic finite elements. The second region is treated numerically as linear elastic. Using this domain decomposition approach, the computing time can be reduced. As reported in [10], the CPU-time for SPIF of a 12 mm deep frustum of a pyramid was reduced from 12 hours to 6 hours. Even if the CPU time is reduced by a factor of 50%, virtual try-outs for AISF do not seem possible in an industrial context due to CPU times.

3 Approaches based on hybrid incremental sheet forming

From the assessment of the approaches to overcome the process limits in AISF, the limitations of standard AISF can be summarized as follows:

- There are no viable approaches that limit the sheet thinning and improve the geometric accuracy, especially for complex industrial geometries.
- The long forming time reduces economic effectiveness.
- There are no reliable and fast planning tools that allow for the definition of optimal forming strategies. FEA is inuseable due to long CPU-times.

Overcoming the mentioned process limits has been focus of research and development in the last 20 years, but no viable general solution has been found. This paper produces ‘hybridization’ of AISF as a possible way to overcome the current limitations. In this way, the process combinations of AISF with stretch forming ‘SF+AISF’ and laser assisted AISF ‘Laser+AISF’ have been developed as promising hybrid forming processes for flexible small batch sheet metal forming. Another interesting aspect of hybridization is the development and processing of hybrid material combinations. As an example of processing of hybrid materials, incremental sheet forming of hybrid aluminium-steel blanks is presented.

‘SF+AISF’. As shown in Fig. 5, with the combination of AISF and stretch forming, a pre-form is created first by stretch forming. A subsequent AISF process completes the forming operation by forming features like corrugations or grooves that are not formed during SF. As discussed in [11], the following advantages of ‘SF+ASIF’ are expected compared to pure AISF:

- Since SF is faster than AISF, drastic shortening of the process time is expected
- Material flow and sheet thinning in SF are different from AISF. A combination of both processes could allow for a more homogeneous sheet thickness distribution than either SF or AISF
- If SF and AISF are applied simultaneously, the tensile forces from SF should reduce the residual stresses created by the cyclic bending deformation produced by AISF

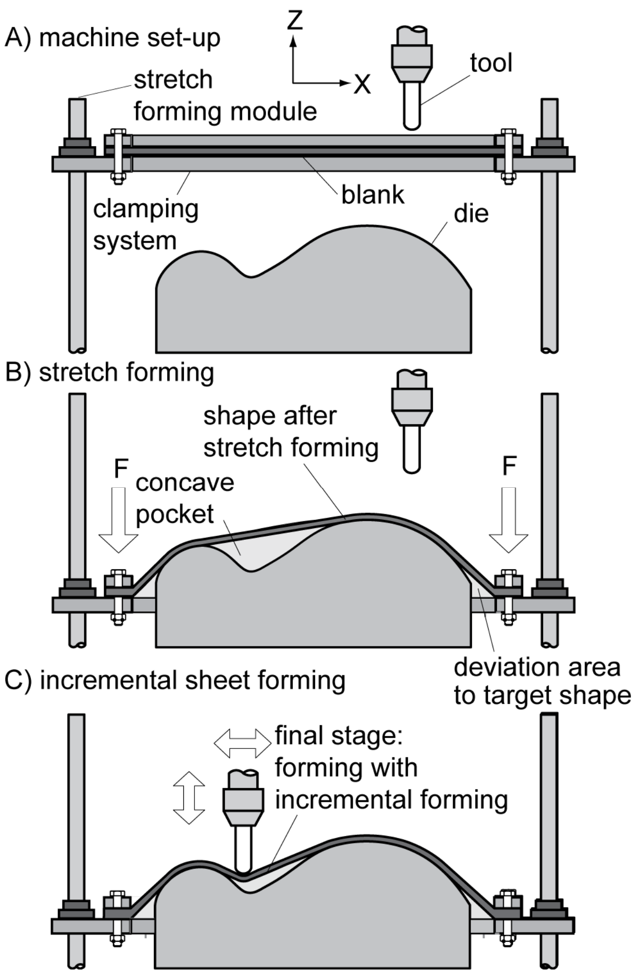


Fig. 5: Principle of the process combination 'SF+AISF' [11].

In order to apply the process combination of SF and AISF, a new machine set-up and CAX-process chain (CAD/CAM/CAE) are needed, that will be introduced in the next section. First results are presented that corroborate the hypothesis set out above.

Laser-assisted AISF. It was shown in the past that the process mechanics of AISF extend the formability of most aluminum alloys and steels at room temperature [12]. This effect does not transfer to Ti- and Mg alloys which typically show limited formability at room temperature due to their hexagonal structure. To increase their formability, sheet metal forming has to be performed at elevated temperatures. One possibility of heating the sheet is local laser heating. The following technical advantages of laser-assisted AISF are expected:

- Increase of formability for sheet materials that are hardly cold-workable.
- Extension of geometry and application spectrum of AISF.
- Increase of geometry accuracy.

The development of laser-assisted AISF aims at providing a cost-effective, flexible forming process for parts made from sheet materials like titanium alloys which are often processed using expensive forming operations such as superplastic forming. Thus, laser-assisted AISF contributes to the individualized production of special sheet materials that are needed for instance in the aeronautical sector and in implants for medical applications.

In order to apply 'Laser+AISF' and corroborate the above mentioned hypotheses, additional developments and research work as described below are required:

- Development of a dedicated laser optic and its integration in the machine set-up.
- Analysis of material characteristics and mechanisms in warm forming.
- Development of heat treatment strategies by laser radiation.
- Set-up of a thermo-mechanical coupled FEA.

Processing of multi-material blanks. The processing of multi-material sheets is investigated as an example for the processing of hybrid materials. The application of multi-materials in sheet parts aims at the realization of lightweight design. Incremental forming of aluminum-steel bonds should provide a possibility to produce individualized hybrid parts in small batches. For this purpose, the qualification of joined aluminium-steel sheets for forming via AISF will be performed by first experimental tests in this paper.

4 Development of a forming machine for hybrid incremental sheet metal

4.1 Process combination of stretch forming with AISF

Machine set-up. For the application of the process combination ‘SF+AISF’, a new forming machine has been set-up at the Institute of Metal Forming (IBF). The new hybrid machine is a combination of a 5-axis portal milling machine with four independently operated stretch forming modules. Each SF-module has two independent axes (horizontal and vertical axes). Hence, the machine has 5 CNC axes for AISF and 8 additional CNC axes for stretch forming (see Fig. 6).

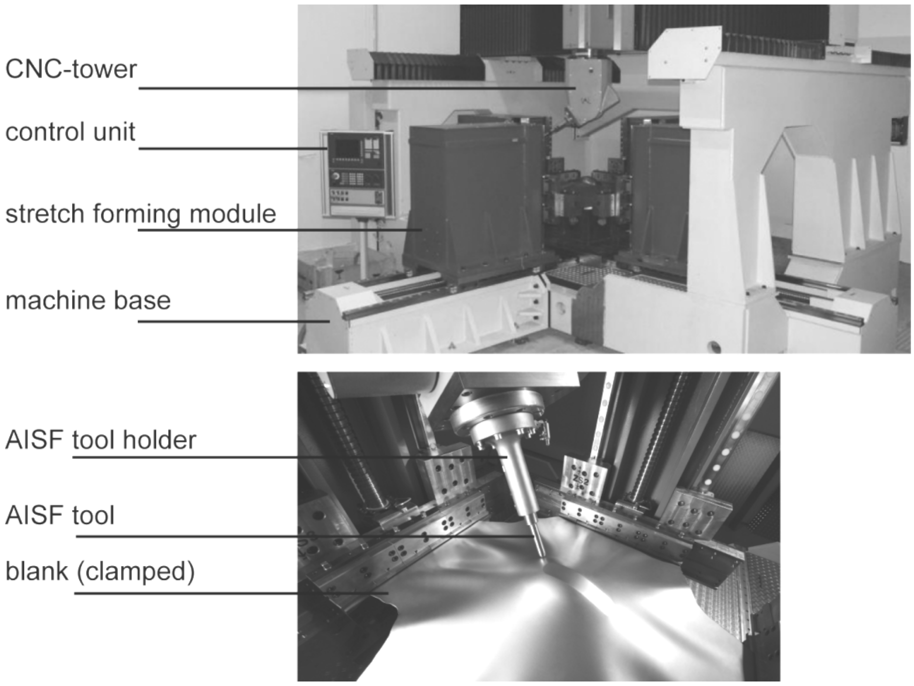


Fig. 6: Hybrid forming machine at IBF.

CAX-Development. In order to save forming time in ‘SF+AISF’ compared to conventional AISF, first the portion of the SF operation has to be maximized by minimizing the portion of AISF operation. Second, ASIF should only cover areas that do not correspond to the final shape after SF. Hence, for a minimum time per part, the identification of the AISF regions is mandatory. Since analytical calculations of the thickness distribution and geometry after SF are not viable for complicated shapes, finite element modelling is applied. In [11], a dedicated CAX-process chain has been introduced that combines CAD, CAE, and CAM (see Fig. 7).

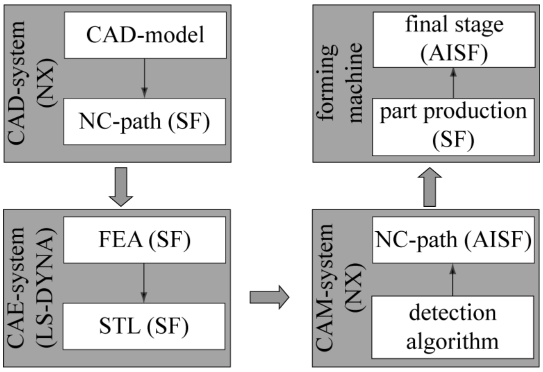


Fig. 7: CAX process chain [11].

The application of the above depicted CAX-process chain enables the reduction of process time and provides NC-codes for both SF and AISF. The scheme is divided into four parts: (i) preparing the geometry in the CAD system Unigraphics NX©, (ii) SF simulation in LS-DYNA© that yields the shape and thickness distribution after SF, (iii) a detection algorithm in Unigraphics NX© that determines the areas of the shape after SF (predicted by LS-DYNA©) that have to be formed by AISF and the generation of appropriate AISF tool paths, (iv) and finally, the production of the part in the hybrid machine.

Results for forming time. In order to analyze the impact of the process combination 'SZ+AISF' on forming time, a demonstrator part has been defined and was produced once using the combined process 'SF+AISF' and pure AISF from 1.0 mm mild steel DC04 blanks. A complete report about the results obtained for the demonstrator part can be found in [13].

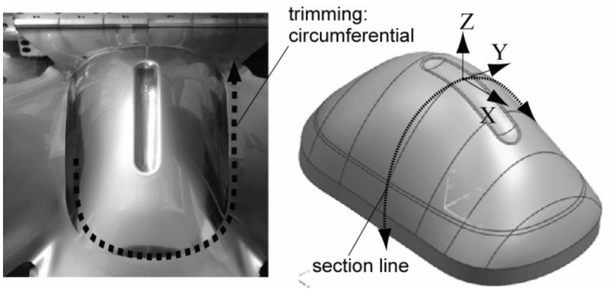


Fig. 8: Manufactured demonstrator by 'SF+AISF' (left) and CAD-model of the die (right) [13].

The production of the part with pure AISF took 60 min., whereas the production with 'SF+AISF' took 40 min. By means of the investigated demonstrator, it was shown that the combined process 'SF+AISF' can indeed reduce the process time.

Result for sheet thinning. The sheet thinning of the demonstrator part mentioned in the previous paragraph has been determined using the optical measurement system ARGUS from gom company (see [13]). The section line on the right side of Fig. 8 has been evaluated in terms of thickness reduction after forming and is depicted in Fig. 9. In the case of pure AISF, it can be seen that thinning increases with an increase in wall inclination. In contrast, with ‘SF+AISF’ the thickness profile remains roughly homogenous. The absolute value of the thickness reduction amounts to approximately 20 % for ‘SF+AISF’, whereas thinning in AISF reaches almost 60%. In summary, the results show that sheet thinning was reduced considerably for the demonstrator part using the process combination ‘SF+AISF’.

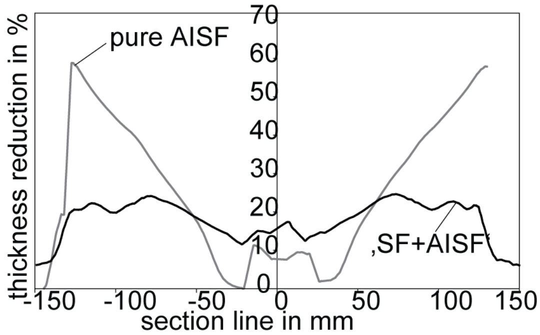


Fig. 9: Thickness reduction.

Results for geometric accuracy. The effect of the combination ‘SZ+AISF’ on the geometrical accuracy was studied by producing a real industrial part, namely an inboard door panel of AIRBUS A320 from 1.0 mm mild steel DC04, (see Fig. 10). The selected part was manufactured with conventional AISF as well as with ‘SF+AISF’. After forming and trimming operations, both parts were digitised by the system ‘ATOS’ from gom company. The comparison of the digitized parts to the CAD-model yielded the actual geometric deviations. The middle of Fig. 10 shows the evaluation of the geometric deviation along a longitudinal section. Consequently, the process combination ‘SF+AISF’ yields a higher dimensional accuracy than pure AISF due to the superimposed tension stresses through SF. Basic study by means of FEA should picture the state of the stress during and after forming.

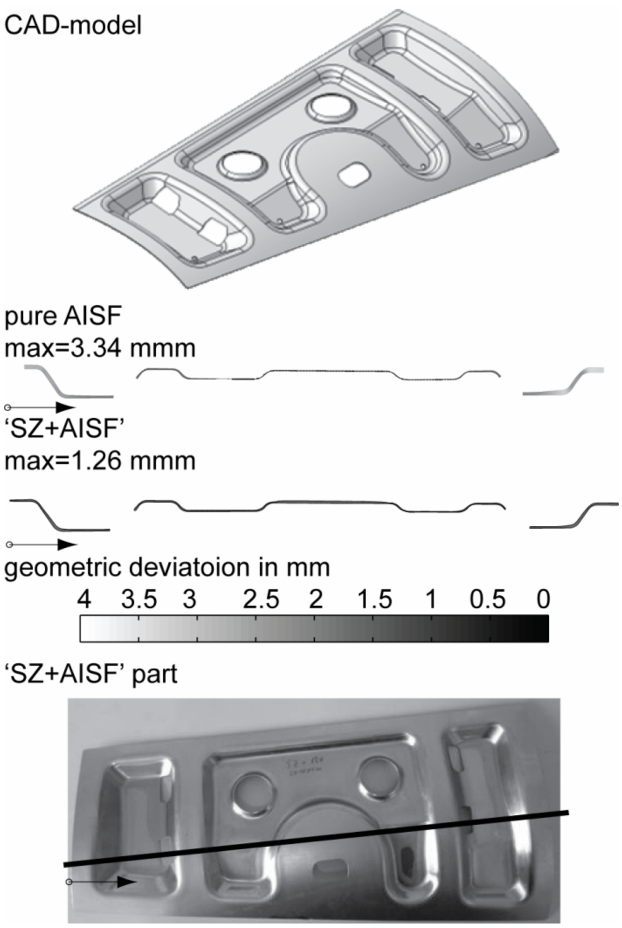


Fig. 10: Inboard door panel of AIRBUS A320.

4.2 Hybrid process: Laser assisted AISF 'Laser+AISF'

Laser optic development and integration into the hybrid machine. The approach of heating the forming zone by laser radiation has also been investigated by Duflou et. al. [14]. Duflou et al. apply laser heating on the underside of the sheet metal. In contrast to that, a different set-up is presented now that has been developed in cooperation between the Institute of Metal Forming (IBF), the Fraunhofer Institute for Laser Technology (ILT) and the Chair for Technology of Optical Systems (TOS). In the new set-up, the laser optic is mounted on the forming tool holder to heat an area on the surface ahead of the forming tool. In this approach, the laser spot and the forming tool act on the same side of the sheet metal. The advantage of this approach is that forming with a die underneath the blank is possible. As a first step in the development of the hybrid process, a concept study for the laser optic was conducted, which was reported in a recent paper [15]. Fig. 11 shows the selected concept of the laser optics. This concept is based on the lateral displacement and subsequent rotation of the laser beam by means of mirrors and rotating lenses within the optics. The incoming laser beam is split up and guided around the AISF tool. The interference of the individual beams on the sheet metal creates the laser spot, which can be rotated on a circle around the forming tool. Circular and elliptical laser spot shapes are available with the new optic. The position of the spot can be controlled by displacing the components in the laser optics.

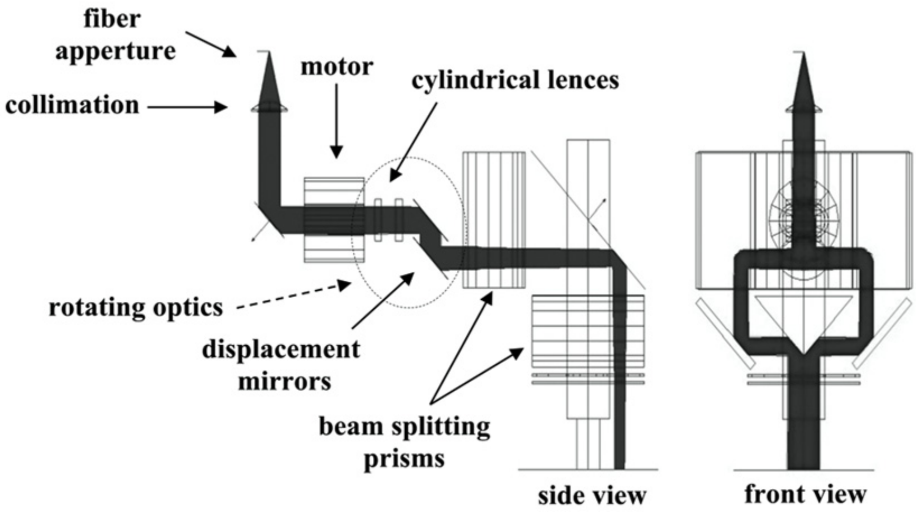


Fig. 11: concept of coaxially rotating elliptical-shaped laser beam distribution [15].

After the optic construction, its integration into the new hybrid machine has been conducted. Fig. 12 shows the built-up laser optic mounted on the spindle sleeve of the hybrid machine. The control of the laser spot, or rather its rotation, was added as an additional axis into the basic control system of the hybrid machine. An algorithm was implemented in Unigraphics NX© to calculate the NC-code for the laser spot based on the AISF tool path. Detailed descriptions can be found in [15].

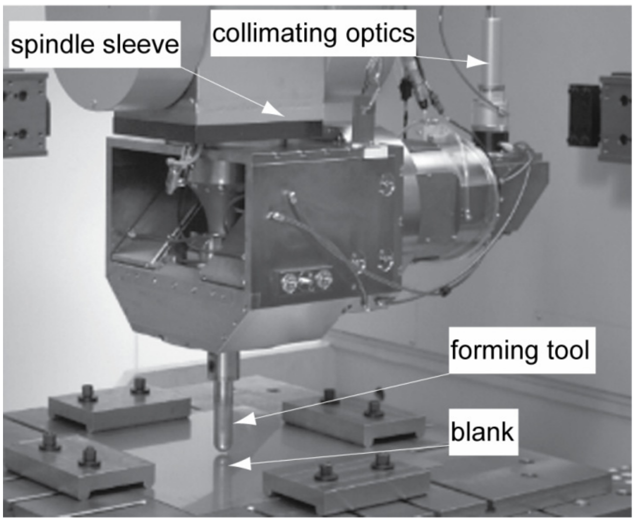


Fig. 12: Integrated laser optic.

Investigation on formability. Parallel to the development of the optics, some preliminary tests were carried out on a conventional incremental forming machine at the IBF (see [13]). For this purpose, elongated pockets were shaped into various sheet metals: 1.0 mm Titanium grade 2, TiAl6v4 and MG-AZ31B. Fig. 13 shows the tool path used for the experiments. The AISF tool started forming and heating at position ‘a’ and proceeded to point ‘b’. On return (b →a), the laser was switched off. The plastic deformation applied was obtained as the sum of all single strokes of the tool with a constant tool pitch of 0.35 mm. The experiments were stopped as soon as material failure occurred.

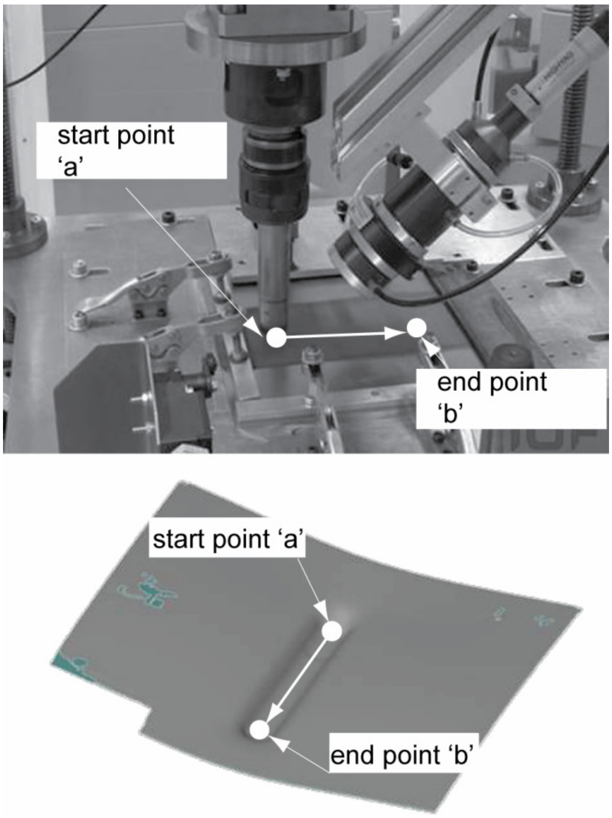


Fig. 13: Tool path sequence [13].

The evaluation of the viable forming depth at elevated temperatures compared to room temperature is depicted in Fig. 14. The hot forming of Titanium grade 2 yielded an increase of about 10 % in forming depth. For TiAl6V4, an increase of forming depth of 19% was observed. In contrast, the formability of the magnesium alloy AZ31 was considerably increased: the viable forming depth could be raised by about 140%.

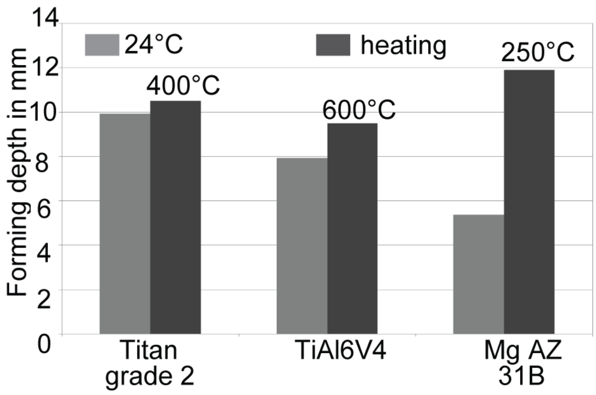


Fig. 14: Evaluation results of forming experiments.

After the integration of the laser optic into the new hybrid machine, the formability of TiAl6V4 was investigated further (cf. [15]). As shown in Fig. 15, a doubly curved pyramid with a wall angle of 60° and a depth of 110 mm was selected as demonstrator part.

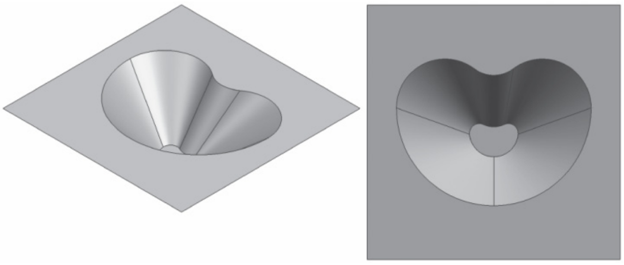


Fig. 15: CAD-geometry of the test shape [15].

The visual result is depicted in Fig. 16. The part manufactured at room temperature showed rupture at 16 mm forming depth. Compared to the part made at room temperature, the part made at elevated temperature of approximately 450° yielded a forming depth of 98 mm which indicates an increase of 512 %. In summary, it could be shown qualitatively that laser-assisted AISF improves the formability of hardly cold-workable material like TiAl6V4 and Mg AZ31B.

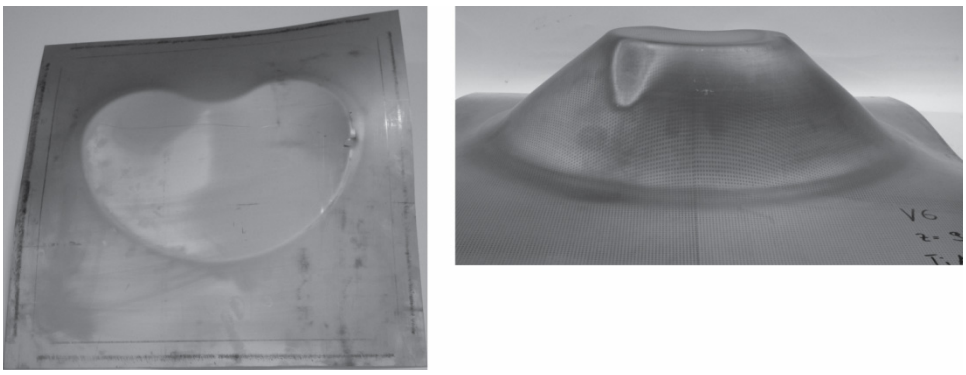


Fig. 16: produced pyramid from TiAl6V4 material at: room temperature (left) and ca. 600° (right).

Investigation on forming mechanism of Mg-AZ31B. In the current work, the mutual effects of initial grain size, speed of deformation, and amount of deformation at an elevated temperature of 250 °C were investigated the laser-assisted AISF of Mg AZ31 sheets. The idea was to develop simple mechanism maps in which higher degrees of formability could be planned through a guided adjustment of the process parameters. For this purpose, as depicted in Fig. 17, the set-up shown in Fig. 13 has been used to form a straight staircase-shaped line composed of 6 steps from 1.0 mm Mg AZ31 sheet.

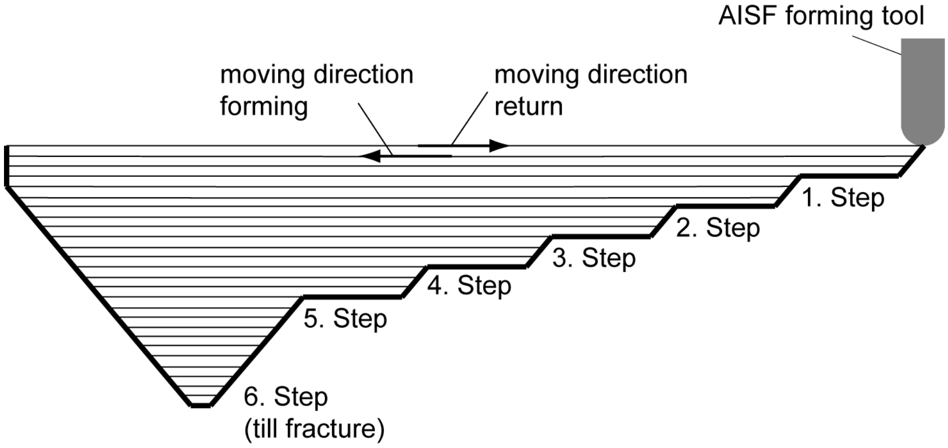


Fig. 17: The schematic representation of the stepwise deformation setup.

In order to thoroughly analyze the occurrence of specific deformation mechanisms and the variations in the intensity of their activation, specimens have been taken from every formed step for microstructural investigations. The step-wise deformation was used to create a better understanding of the microstructural changes during consecutive passes of deformation from the beginning until crack formation (Fig. 17). Microstructural investigations, X-ray texture analysis, and micro-hardness testing were used along with measurements of the thickness-reduction (Fig. 18).

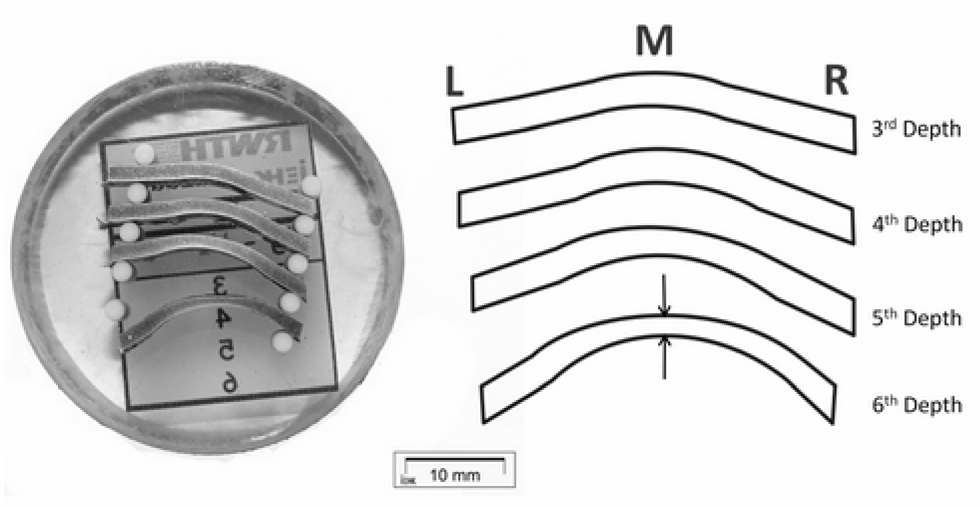


Fig. 18: The mounted cross-sections of the deformed sheets in the 3rd to the 6th depth used for the measurements of the thickness-reduction.

The high-temperature activation of several slip systems, dynamic recrystallization (DRX), and grain-boundary- sliding are conventionally known as the main targets for an increased formability in Mg AZ31 alloy [16,17].The initially developed map of DRX-formability-deformation Speed (Fig. 19) showed that the zones of highest formability (> 40% thickness-reduction) very well overlap the zones of highest activation of DRX (40-45% DRX) and that the highest formability was achieved when the intermediate speed of ‘laser-assisted AISF together with the finest as-received grain-size was used.

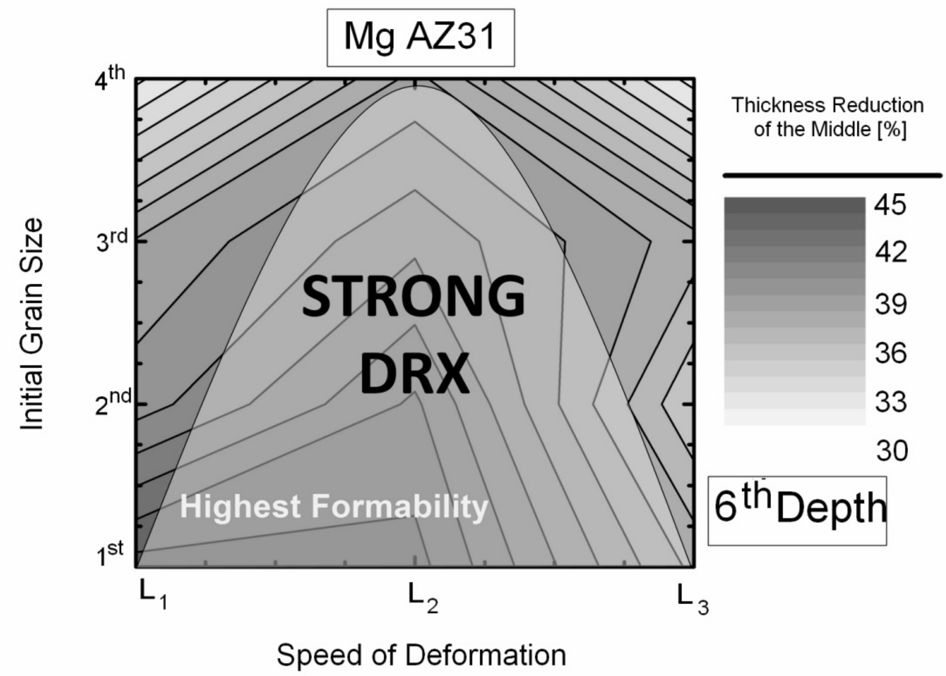
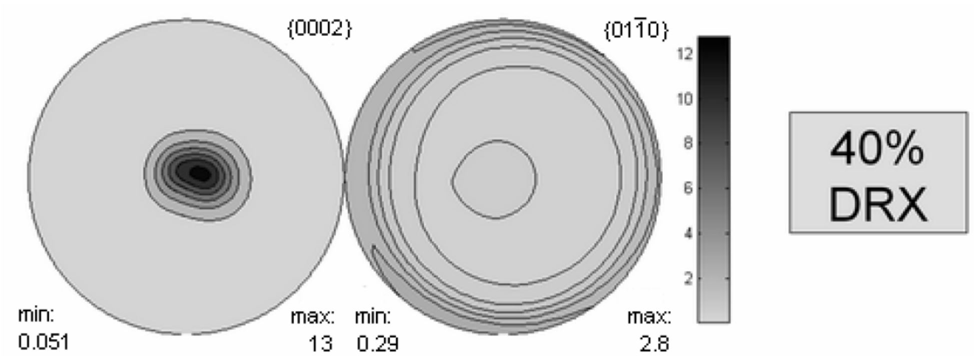


Fig. 19: The developed map of DRX-Formability-Deformation Speed for the Mg AZ31 sheets formed during the LISF process.

In addition, texture analysis and optical microscopy results showed a minor activation of prismatic slip, and an intense operation of basal slip together with the possibility of shear-zone formation [18]. Both basal slip and shear-zones were found to enhance the formability of Mg AZ31 sheets during the laser-assisted AISF process (Fig. 20).



Slip System	Basal Slip	Prismatic Slip	Def. Depth
Maximum Intensity	13.0	2.8	6th Depth

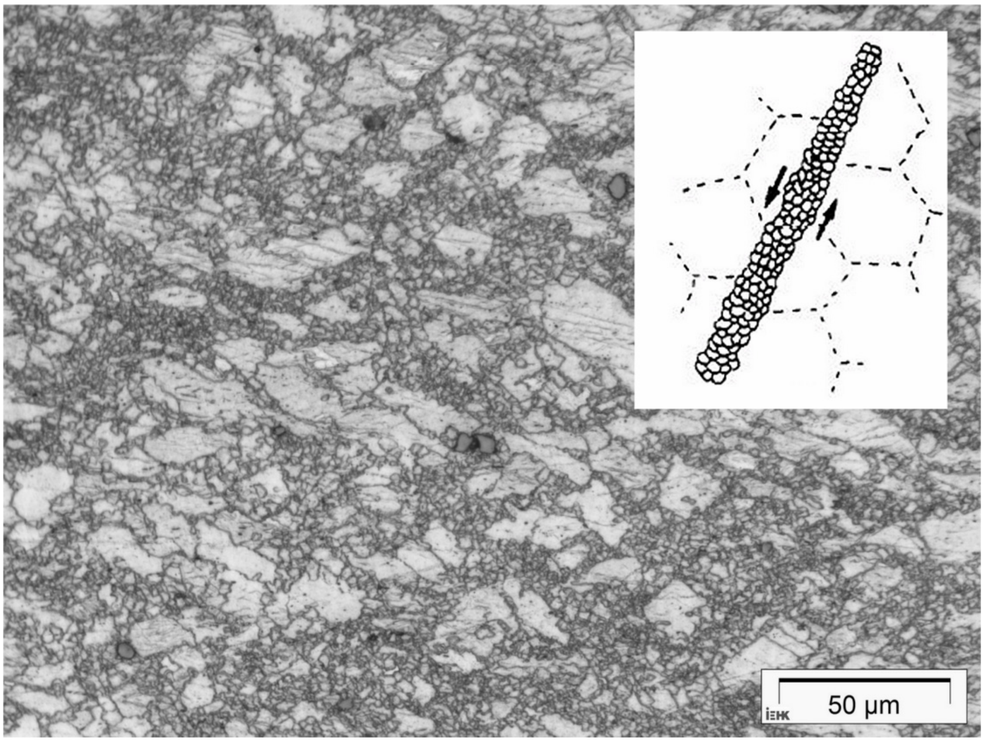


Fig. 20: Top: the high-temperature-intense-activation of basal slip and the comparatively minor-activation of prismatic slip at 250 °C; down: the occurrence of DRX morphology showing the possibility of shear-zone formation.

4.3 Forming of Tailored Hybrid Blanks

To extend the application spectrum of AISF by an innovative application field for lightweight design components, forming of steel-aluminum-tailored-hybrid-blanks (THB) has been investigated. A joining concept for THB that allows for joining of aluminum and steel blanks as butt joint has been developed at the Welding and Joining Institute (ISF). With this joining concept, only the aluminium material is molten during joining while the steel material is maintained in the solid phase. With other words, a dissimilar material joint is performed that is distinguished by welded joint on the aluminum side and a brazed joint on the steel side (see Fig. 21) [19].

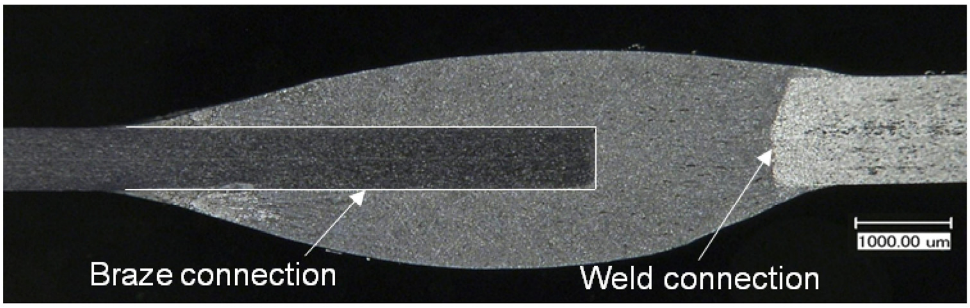


Fig. 21 Braze - weld join of steel (left) and aluminum (right).

An AA6016 (thickness 1.3 mm) aluminum sheet has been joined to a mild steel DC05 sheet (thickness 1.0 mm). Preliminary tensile tests were carried out. Optical strain measurements during the tensile tests showed that during the tensile tests, only the aluminium sheet is stretched considerably while the steel part of the specimen is deformed only to a very small degree (see Fig. 22). The results of these preliminary tests indicate that the different flow stress levels of the jointed materials must be compensated for by different material thicknesses.

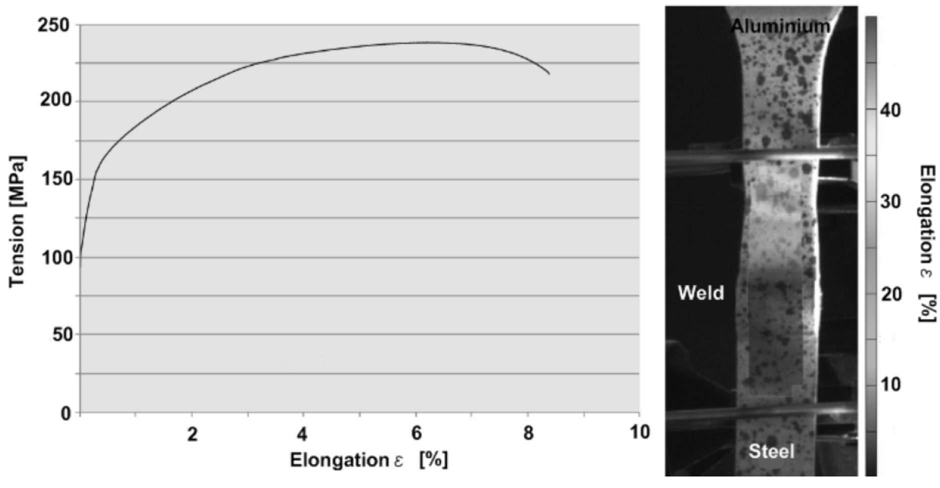


Fig. 22: Tensile test with local strain measurement.

In a preliminary forming test at IBF, a hyperbola geometry was produced using THB consisting of aluminum and steel sheets. The results were compared to the parts fabricated from the base materials. All parts have been formed until fracture occurred and the forming depth at rupture has been identified. The aluminum part allowed a maximum forming depth of 29 mm before rupture. The steel part showed a possible forming depth of 44 mm. In comparison to that, the THB part showed cracks at forming depth of 19 mm which has been observed in the aluminum section of the joint. This corresponds to approximately 65% of the forming depth of the part made from aluminum. This test confirms that the forming of THB is possible but the forming limits of THB seem to be lower than that of the base materials.

In contrast to the hyperbola geometry that exhibits non-constant wall inclination, as depicted in Fig. 23, a sound frustum of pyramid of 50 mm depth and 30° wall inclination has been produced using THB (1.3 mm AA6016 and 0.75 mm DC05) as demonstrator for a hybrid product. While AISF seems to allow for forming of hybrid materials, it seems necessary to increase the formability of the joined and to understand the process mechanics of forming hybrid materials. A possible alternative to forming joined hybrid materials consists of forming individual monolithic sections and joining after forming.

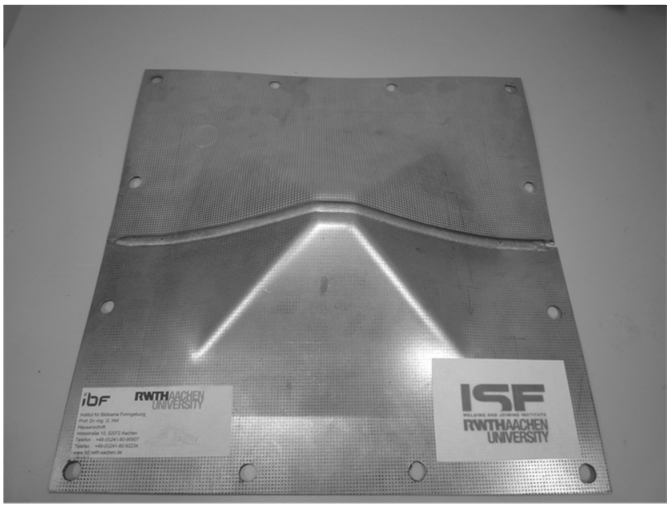


Fig. 23: Steel-aluminium pyramid produced by AISF.

5. Summary and conclusions

The combination of AISF and stretch forming and laser assisted AISF as hybrid processes, as well as the forming of hybrid aluminum-steel blanks was put forward and investigated by an interdisciplinary team at RWTH-Aachen University.

For ‘SF+AISF’ it can be concluded that, compared to pure AISF,

- a noticeable reduction of production time has been achieved,
- less sheet thinning is produced
- the dimensional accuracy is increased and
- virtual try-outs based on CAX are possible.

Compared to cold AISF, for laser-assisted AISF it can be concluded that the formability of Ti- and Mg-alloys seems to be extended by laser heating. However, the knowledge of the deformation mechanisms that are active in warm forming is mandatory for successful part production.

The forming of aluminium-steel blanks by AISF shows that forming of the THBs is possible. However, the formability of THBs made of aluminum and steel seems to be lower than that of the base material. An optimization of the joining concept especially with regard to pore minimization and improvement of wetting properties of the joint is required. Afterwards, application components shall be formed. A close future cooperation of the partners from different disciplines is required in order to achieve the defined goals.

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