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# Influencing the Forming Limits in Air Bending Using Incremental Stress Superposition

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**Abstract.** Restricted forming limits of modern high strength steels are a big challenge in manufacturing engineering and crucial in sheet metal bending processes. Looking for solutions for this problem, different modifications of the air bending process have already been developed. The innovative process of incremental stress superposition on air bending is one of these modifications. Studies of this process alternative show a positive effect on the considerable reduction of the sheet metal springback and the efficient extension of forming limits of materials. Using the principle of incremental stress superposition leads to several advantages compared to conventional bending processes. The bending force and, therefore, the consumed energy during air bending with incremental stress superposition are much lower. At the same time the process limits are extended. This paper presents the new process alternative and shows the latest investigation results.

## Introduction

The reduction of fuel consumption is one of the major aspects which have to be considered in the transportation sector. A technological solution within manufacturing engineering is the development of innovative lightweight technologies. Lightweight products in the transportation sector still have to show high safety properties but at the same time also a low weight. These products are mainly used in the automotive industry and in the aircraft sector.

The selection and development of new materials for the manufacture of such structures plays a major role. Currently, high strength steel grades are increasingly used. Due to the higher strength of these materials their springback during bending is high as well. This leads to larger shape deviations which have to be considered during the process design. Furthermore, the high strength steel shows a reduced formability which quickly leads to cracks within the bent part.

Due to the low formability as well as the high springback different bending technologies have been developed to bend sheet metals like bending with a lower punch, bending with an elastomer die or the incremental stress superposition on air bending. When using the principle of incremental stress superposition on air bending several advantages like a much lower bending force and, therefore, lower consumed energy can be reached compared to the conventional bending processes.

This paper discusses the possibilities of the incremental stress superposition on air bending and shows how it extends the forming limits and improves the component properties.

## Incremental Stress Superposition on Air Bending

Methods for increasing the process limits in sheet metal bending are based, on the one hand, on the application of additional heat (Fig. 1a) and, on the other hand, on the application of a hydrostatic stress state (Fig. 1b). This can be implemented in both cases locally or globally. When heating the workpiece both methods are delivering similar results concerning the process limits [1].

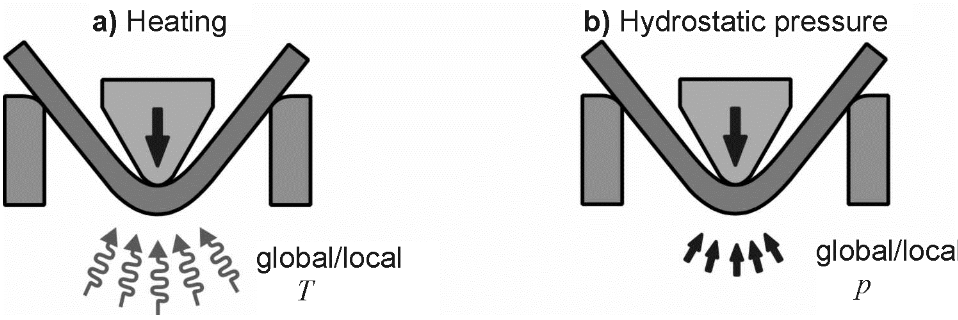


**Figure 1:** General methods to increase the forming limits in sheet metal bending [2]

The disadvantages of heating are the additional process steps, the cooling of the sheet and the related resulting lower energy balance of the process. Moreover, the material structure and the mechanical properties could change by the incorporation of the heat [3]. The application of a hydrostatic pressure can be realized through using appropriate technological tool elements in the forming zone. By means of these tools the stress state can be changed. In this way the stored elastic energy in the bent part, which causes its springback, is drastically reduced at the cost of a higher plastic portion. At the same time the tensile stresses in forming zone are reduced which also reduces the risk of crack initiation. Due to the stored compression energy the forming limits of components are increased. The idea of using hydrostatic pressure to generate a local or global stress superposition is already used in various sheet metal forming processes. An overview of the common sheet metal bending processes without and with stress superposition is shown in Fig. 2.

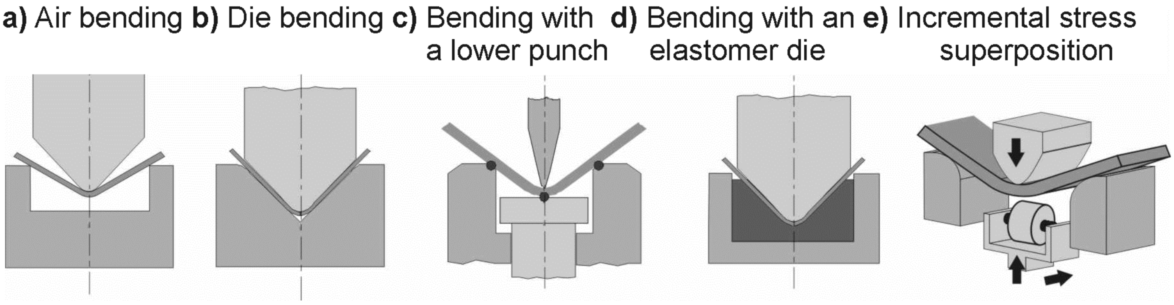


**Figure 2:** Sheet metal bending processes without (air bending) and with stress superposition [2]

The most common sheet metal bending processes are air bending and die bending. In air bending (Fig. 2a) the final product geometry (bending angle) is solely achieved through the specific displacement of the punch. In die bending (Fig. 2b) the final product shape is obtained by closing both tools (punch and die) and coining the sheet metal in the die with a high force causing a compressive stress superposition. This results in increased process limits. Bending with a lower punch (three point bending) represents an extension of the conventional air bending, in which an additional load is applied in the forming zone using an adjustable lower punch. The load of the lower punch can be applied continuously during the bending process (Fig. 2c). The principle of bending with an elastic die (Fig. 2d) is based on the replacement of the rigid die of the die bending process by an elastic die, which mostly consists of an elastomer. The rigid punch presses the sheet into the elastic die, which is thereby gradually displaced causing a stress superposition in a big zone of the blank. A new alternative for springback compensation is the incremental stress superposition (Fig. 2e). Here, the stress superposition is restricted to a very small area by means of a lower roll. The process is described in the following.

For all three methods presented in Fig. 2b to Fig 2d, the application of stress superposition is uniform over the sheet metal length. The disadvantage of these methods is that along the bending edge some bending angle deviations can occur. This leads to a loss of quality. This may be bigger the wider the sheet is. The reasons for these angle deviations are, on the one hand, the inhomogeneities of the mechanical properties in a sheet, and, on the other hand, the deflection of the press brake during the forming process. This effect depends directly on the applied bending force, which increases by usage of materials with a high strength. The angular deviations can be compensated by a correction of the punch path or a crown of the machine table. Local adjustable crowning systems are very complex and expensive. To control the crowning also precise knowledge of the local real present plate material properties and the parameter correlations are required.

For these reasons, a new method was developed at the IUL; the air bending process with incremental stress superposition (Fig. 2e) [4]. This new method starts with the conventional air bending process and is followed by a stress superposition which is created by a lower roll moving along the outer side of the blank. The feed is 10mm/s and roll compression speed is 2mm/s. After the incremental stress superposition the unloading operation takes place. A detailed description of the experimental set up and first results of reducing the springback using this new method were already presented in [5]. In [2] a comparison of the different bending processes air bending, die bending, bending with lower punch, bending with an elastomer die, and incremental stress superposition has been made with equivalent process conditions. As a result of this investigation, the incremental stress superposition requires a comparatively low force and, therefore, less energy to reach the same springback reduction. A significant springback reduction of over 85% can be achieved. In [6] the usability of the process for bending tailored blanks is demonstrated.

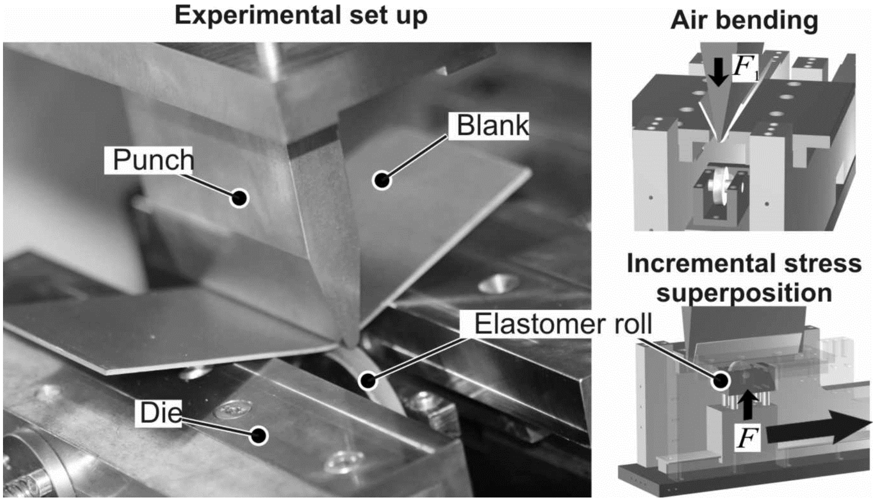


**Figure 3:** Experimental set up and the principle of the incremental stress superposition [5]

### Extension of the Forming Limits

Another aspect in the evaluation of forming processes is the achievable forming limits. The approaches used previously (only once stress superposition after the loading) do not show any improvement. The first reason is that using an elastomer roll to extend the forming limits does not function as well. In this case the required stress to extend the forming limits is so high, that the elastomer roll generates an additional bending moment $M_b$* (Fig. 4a).

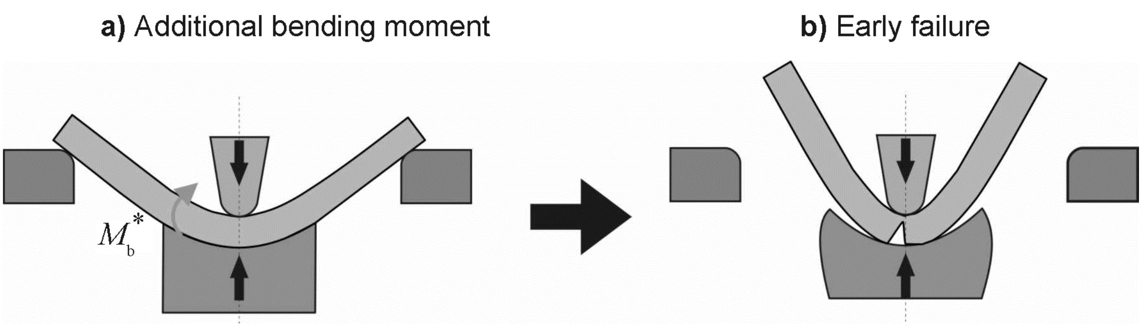


**Figure 4:** Appearance of component failure in bending with an additional bending moment $M_b$*

Thus, the bending process is accelerated and the stress superposition does not have time to reduce the tension stresses within the part. As consequence, a failure cannot be prevented (Fig. 4b).

This problem can be avoided if, instead of the elastomer roll, a steel roll is used. The second reason is that applying only once the stress superposition is not enough to reduce the development of cracks. Significant changes, however, result in a modification of the process execution, as sketched in Fig 5. The lower roll starts to apply the stress superposition from the beginning of the air bending process (Fig. 5a). Once the bending process starts, the incremental stress superposition is initialized at the same time (Fig. 5b). When the punch roller reaches the end of the plate, it returns again (Fig. 5c). This procedure is repeated (Fig. 5d) until the bending process is completed.

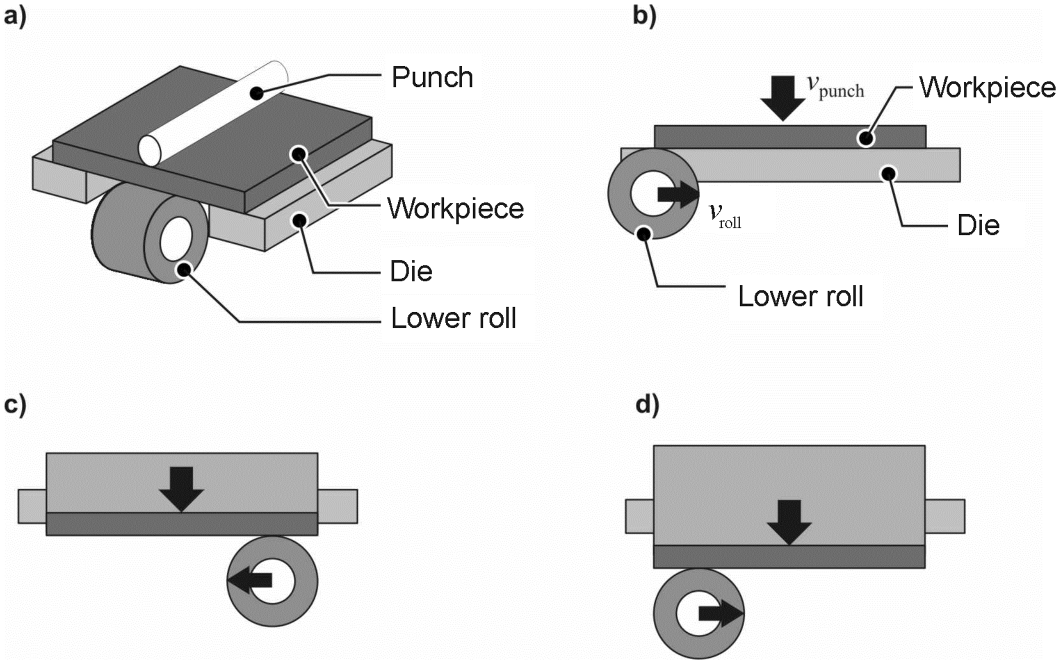


**Figure 5:** Modified process for the extension of the forming limits using incremental stress superposition

Fig. 6 shows an example of two bent samples of DP1000, one of which has been conventionally bent using air bending and the second one bent with the modified incremental stress superposition. A failure of the air bent part is clearly visible in the prepared cross section (Fig. 6a).

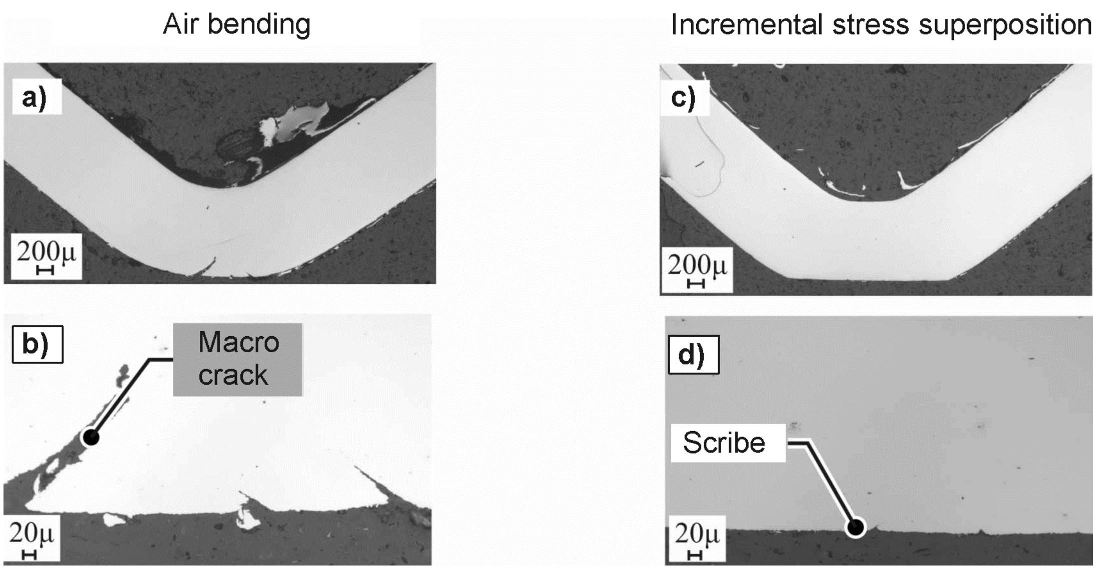


**Figure 6:** Microscopic view of the transverse section with and without stress superposition

In addition to the marked macro-crack, two other micro-cracks could be observed by a higher magnification (Fig. 6b). In this case, there is a clear failure of the component and the bent part cannot be used anymore. In contrast to this behavior the bent sample with stress superposition do not show any cracks with a 100x magnification (Fig. 6c). Only with a 200x magnification just a very small scribe is recognizable (Fig. 6d). Solely a flattening of the workpiece is visible. This flattening is caused by the stress superposition using a steel roll. The reduction of cracks using stress superposition can be explained in that way, that during the air bending process the voids within the specimen can first grow and then develop into a macro-crack. On the other hand, the modified continuous process causes that the voids can only grow in the substantial shorter time in which the lower roll do not apply locally the stress superposition. When the lower roll applies again at the same place the stress superposition the influence of the already extended void is considerably lower. Thus, the voids do not have the possibility to grow or to get connected to a macro-crack. To achieve this behavior the punch velocity must be higher than the horizontal velocity of the lower punch. Otherwise the expansion of the voids cannot be reduced and despite of the stress superposition the risk of failure of the workpiece still exists.

## Component Properties

A further aspect in the evaluation of forming processes is the properties of the formed components. Fig. 7 shows an example of two bent workpieces of DP600, one of which has been conventionally bent using air bending and the second one bent with the incremental stress superposition. In the air bent workpiece the material structure meets the (theoretical) expectations. Inside the part (i) a laminar structure has been established through die compression. At the centre (ii) a small change of the microstructure is shown. At the outside zone (iii) a stretching of the material structure through the tensile stresses can be seen. When superposing stresses the laminar structure of the inside workpiece zone (a) becomes again globular through the additional compression stresses. In the area of the initial neutral fiber (b) the material structure is compressed. At the outside zone (c) a clear compression of the microstructure can be seen. A homogenization of the microstructure in the influencing zone of the stress superposition is, therefore, reached.

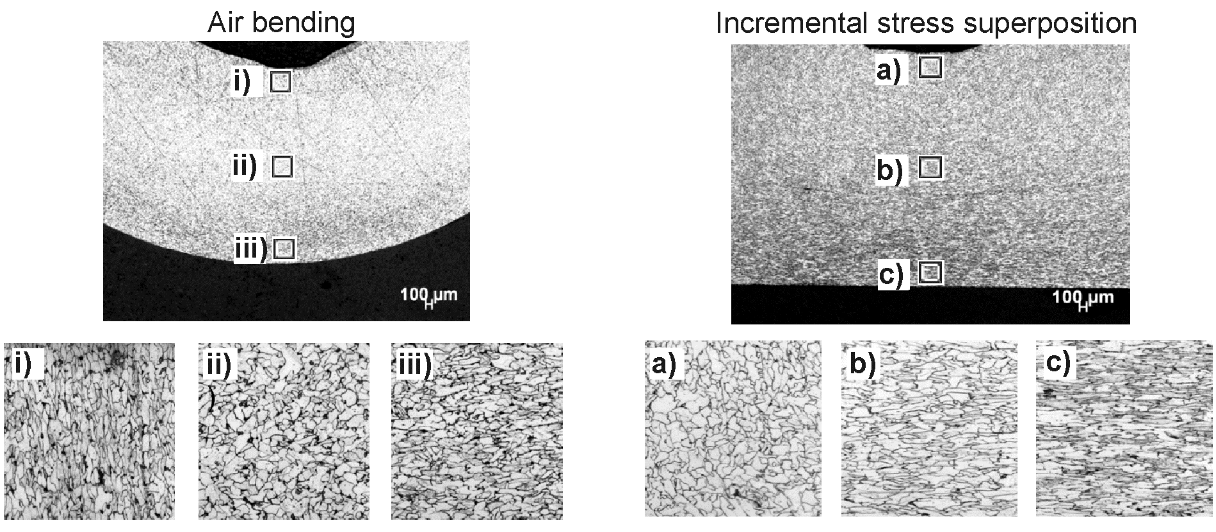


**Figure 7:** Microstructure of components bent with and without stress superposition

Fig. 8 shows the microhardness of components of two different materials bent with and without stress superposition. The reference lines represent the hardness values before bending. For both materials the typical hardness distribution with hardly a change of the hardness at the neutral fiber, in comparison with the initial material, and increasing values towards the sheet metal inner and outer areas caused by cold hardening is established after the air bending process. After stress superposition the hardness distribution is almost uniform over the sheet metal thickness with hardness values which approximately correspond to the hardness levels at the inner and outer zones of the air bent components.

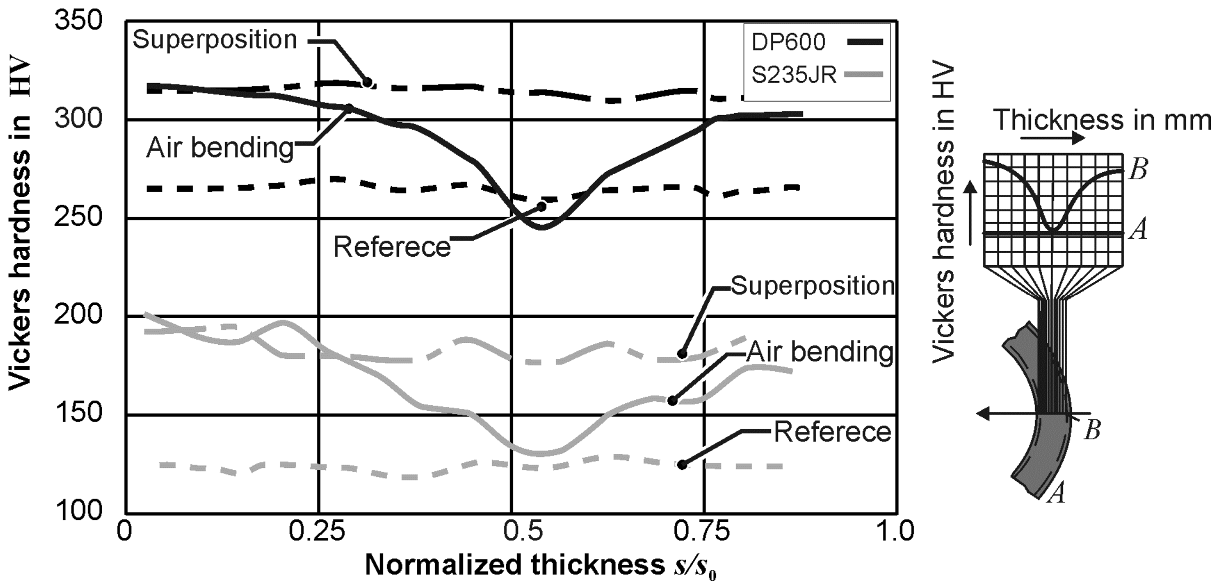


**Figure 8:** Microhardness of components bent with and without stress superposition

## Conclusion

The incremental stress superposition on air bending shows a high potential. Lower forces and, therefore, less energy is needed to reach a similar springback reduction as in other established bending processes. Furthermore, the forming zone is influenced in such a way that the formation of cracks is avoided, extending, therefore, the forming limits. Last but not least, the components bent by the new process variant show better material properties. A homogenization of the microstructure in the influencing zone of the stress superposition and a homogeneous hardness distribution over the sheet metal thickness are the results of this flexible process.

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