APPLICATION OF THE SHOT PEEN FORMING PROCESS TO SANDWICH- AND LAMINATE STRUCTURES

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ABSTRACT

Sandwich and laminate materials gain increasing importance for high grade, large, thin and multi-dimensional curved structures. This paper details basic as well as additional industrial scale studies about the applicability of the Shot Peen Forming process to the sandwich-material Hylite. Low-speed indentation experiments are used to characterize geometrical and material influences, e.g. of ball size and material state on the indentation diameter. For their interpretation dimensionless values are used. A comparison between monolithic and sandwich materials on the basis of numerical models shows the fundamental difference between them with respect to forming incidents. In forming experiments in an industrial scale peening facility significant concave curvatures and information about their dependency on material, ball size and coverage are achieved which show the potential of the shot peen forming process and its application to this innovative kind of material.

KEY WORDS Shot Peen Forming, Sandwich- and Laminate material, Hylite

INTRODUCTION

The Shot Peen Forming process is well established for the production of large, multidimensional and curved metallic sheets with relatively large curvature radii typically produced in small lot sizes. Present applications are e.g. structures for the aerospace industry like spherical dome tank segments for ARIANE 4/5-launch vehicles (F. Wuestefeld, 2003).

From the late 1940s until now profound experience has been acquired regarding shot peen forming of aluminium, steel and titanium materials (P. O´Hara, 2003; J. Schulz, 2003). All materials used in production have a monolithic setup in common. During the last decades the main focus of technical improvements in shot peen forming has been laid more on process issues, like reproducibility and controlling, than on expansion to different types of materials. However, newer trends in the Aerospace industry show an increasing diversification in terms of materials for structural components (Aluminium, 2005; G. Marsh, 2006), e.g. for the fuselage, whereby new manufacturing techniques have to be developed or existing to be adapted.

The Shot Peen Forming process can presumably extend the bandwidth of suitable processes for shaping flat multilayered products and reduce the current requirement for a single-part production of structures (T. W. de Jong, 2001). Such significant changeover in terms of material in the shot peen forming process apparently entails the need of research regarding influences on process parameters. This study details basic experimental and numerical analyses to show the potential of the Shot Peen Forming process in the application to the sandwich material Hylite, which offers a good approach for research work due to its simple setup.

METHODS

Material - HYLITE

The sandwich material HYLITE consists of two thin face sheets made of aluminium grade AA5182, which are separated by a comparatively thick polypropylene core. The material of the face sheets can either be "as rolled" – designated as "hard" - or heat treated (soft). Fig. 1 and Tab. 1 gives an overview of the material considered.

Tab. 1: Configuration of HYLITE-material

Name	Overall thickness in *mm*	Face sheet thickness in *mm*	Thickness of intermediate layer in *mm*	Flow stress of face sheet in *MPa*	Elongation to fracture in *percent*
1.2/0.8 HYL soft	1.2	0.2	0.8	140	18
1.2/0.8 HYL hard	1.2	0.2	0.8	380	4

Experimental setup of quasistatic indentation experiments

The aim of this sequence of experiments is the investigation of the influencing parameters, ball size and the material state of the face sheets, on the depth of the indentation of a single ball in a sandwich sheet at slow indentation speeds. Fig. 2 shows the setup of the experiments. The indenter punch velocity is $v_p = 1$ mm / min. The feed is stopped after reaching a user-defined punch force, which is measured by a load cell. For each combination of ball and sheet the force is increased from 100 to 2000 N in intervals of approx. 100 N. The indentation diameter is measured by a measuring microscope with 30 x magnification and a digital distance measurement device. For the interpretation dimensionless values are used (M. Klemenz, 2005).

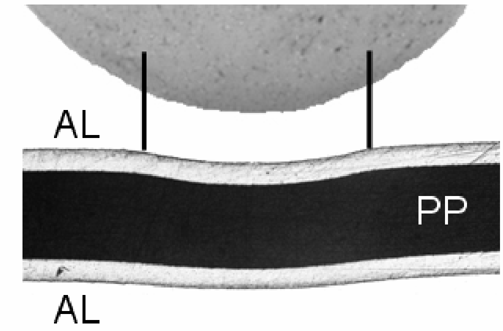

Fig 1: Micrograph of a ball indenting a Hylite sandwich sheet (1.2 / 0.8 soft)

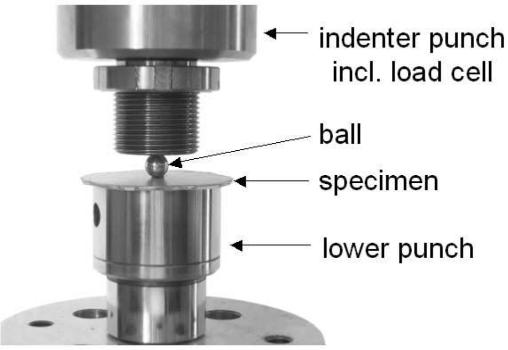

Fig. 2: Experimental setup of quasistatic indentation experiments

Numerical Modelling

The corresponding Finite Element (FE)-simulations for the quasistatic indentation experiments are realized in an axisymmetric ABAQUS/Explicit FE-model (see Fig. 3). The ball composed of rigid RAX2 rigid elements, moves into the sandwich structure which is the material HYLITE 1.2 / 0.8 soft. The indentation speed is 1 mm/min. The ball is stopped after a certain time period and reversed into the opposite direction with the same speed to consider elastic deformation during unloading. The sandwich sheet is divided into domains of the intermediate layer and the face sheets, and the material properties of polypropylene and aluminium are assigned to each region. The element type CAX4R has an element size of 0.04 mm. The sandwich sheet rests upon a base plate with a Young's modulus of 210 GPa and a yield strength of 900 MPa. The friction coefficient is $\mu = 0.1$ in case of the contact between the ball and the upper face sheet and $\mu = 0$ between the base plate and the lower surface of the sheet. All material data are determined in a combination of a tensile test and a corresponding inverse modelling approach to fit yield stress, Young's modulus and slope of the flow curve for the linear elastic-plastic constitutive law used. To show differences between sandwich- and monolithic material simulations of 2 mm thick monolithic AA5182 grade aluminium are added with the same geometric boundary conditions and the identical flow curve of the sandwich face sheets for the entire cross section. Fig. 4 gives an overview over the FE-model. The validation of the models is performed on basis of measured indentation diameters, where good correlations between simulations and experiments are found.

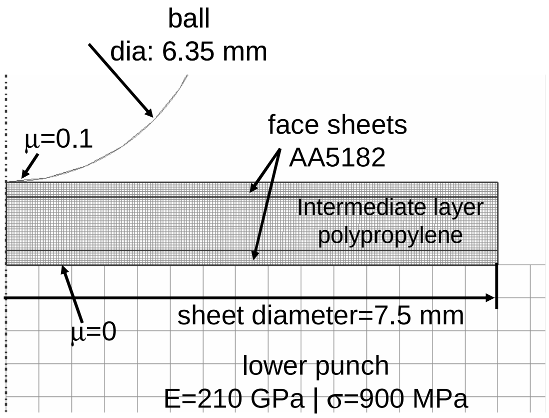

Fig. 3: FE-model of Hylite 1.2 / 0.8 soft

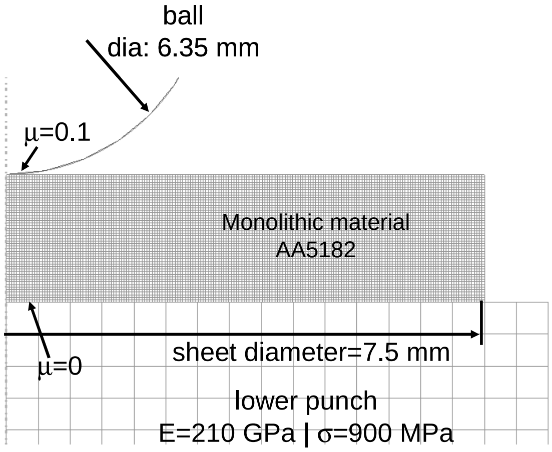

Fig. 4: FE-model of monolithic AA5183

Shot Peen Forming experiments

The purpose of the industrial scale experiments is the identification of important influences on the curvature radius and quantification of possible curvatures. Therefore the following parameters are examined systematically:

- coverage: 50, 75 and 99 %
- ball diameter: 4 mm
- peening pressure: 0.8 – 3 bars
- material: HYLITE-material 1.2 / 0.8 with varying face sheets (see Tab.1)

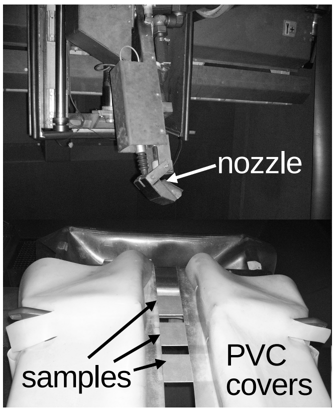

Fig 5: Experimental setup of peen forming experiments, line-up of three samples

All experiments are carried out on the peen forming apparatus shown in Fig. 5. It is equipped with an injector-gravitation compressed air unit for the acceleration of spherical steel balls usually in a diameter range of 4 mm to 8 mm and a peening pressure from 0 to 5 bars. The spiral type nozzle tool path starting from the symmetry axis has a line distance of 6 mm in case of balls with diameter 4 mm and a nozzle diameter of 12 mm. The square samples measure 200x75 mm^2. To fulfil the demand of a locally homogeneous coverage ball hits into the surroundings of the 70 mm wide area to be peened are prevented by thick PVC covers. With respect to the statistical character of the process, three samples of each combination are formed. Generally the profile of the specimen consists of the peened area and unpeened flat areas on both sides. The angle between both unpeened flat sides is measured using a digital goniometer in order to provide a simple and fast measuring method.

RESULTS

Quasistatic indentation experiments

Fig. 6 shows the similarity of normalized indentation diameters versus normalized indentation forces for four different ball sizes. The conformance of all graphs shows a negligible influence of the ball diameter on the normalized indentation diameter. However, as shown in Fig. 7, the course of normalized indention diameters vs. normalized indentation force depends on the flow stress of the face sheet.

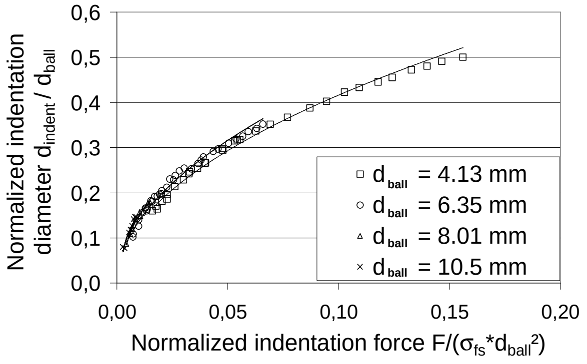

Fig. 6: Influence of the ball diameter d_{ball}= 4.13, 6.35, 8.01, 10.5 mm on the indentation diameter in Sandwich 1.2/0.8 hard

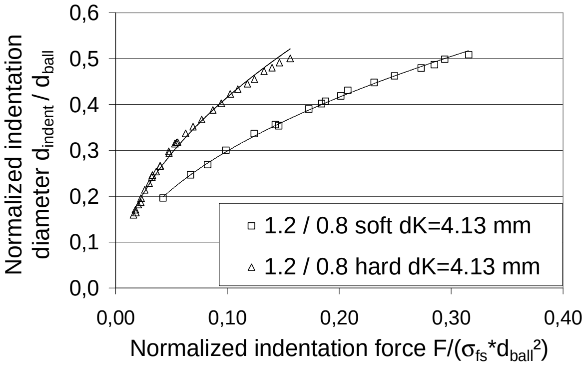

Fig. 7: Influence of face sheet material 1.2 / 0.8 hard and soft on indentation diameter with ball diameter d_{ball}= 4.13 mm

Numerical modelling

Fig. 8 and 9 show the results for the equivalent plastic strain and the nodal displacement for the 2 mm thick AA5182 as well as for the Hylite sheet 1.2 / 0.8 soft and the ball diameter 6.35 mm.

Monolithic AA5182 – 2mm thick

Hylite sandwich 1.2 / 0.8 soft

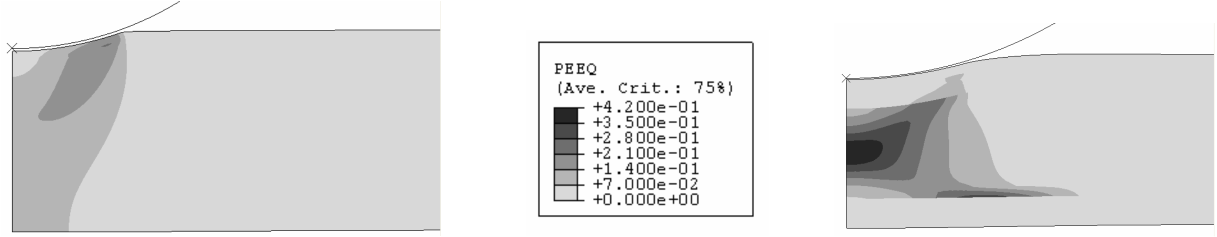

Fig. 8: Equivalent plastic strain

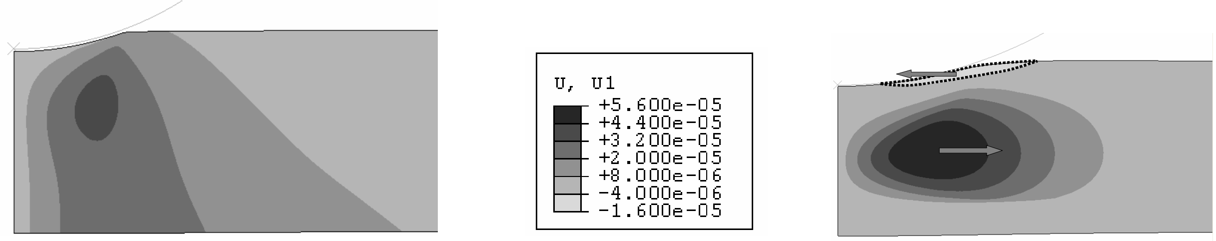

Fig. 9: Radial nodal displacement

While relatively small plastic strains of monolithic materials occur in the material mainly near the upper surface (Fig. 8) higher values of equivalent plastic strain of

Hylite can be observed inside the soft intermediate layer. Important for the Hylite sheet is that material in the contact zone of the ball and the top layer has been radially displaced towards the symmetry axis (Fig. 9)

Curvature radii for HYLITE

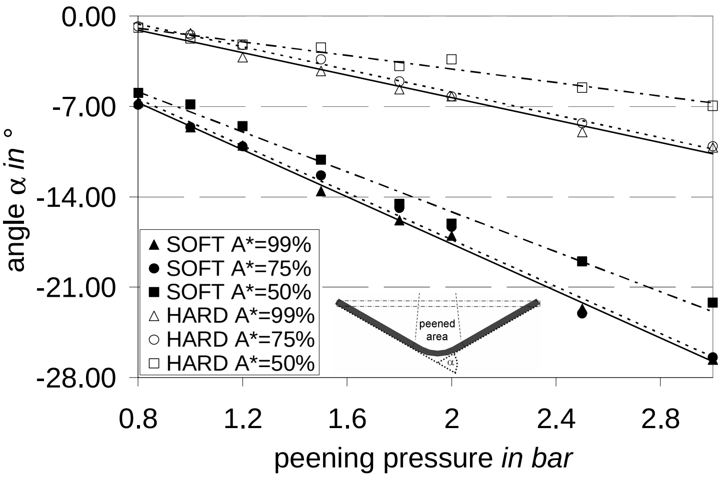

Fig. 10: Angles for 1.2 / 0.8 hard and soft with ball diameter 4 mm. mean value of three samples (peened area: 70 x 75 mm², sample geometry: 200 x 75mm²)

Fig. 10 shows the angle α enclosed between the unpeened areas of the sample. The materials HYL 1.2 / 0.8 soft and HYL 1.2 / 0.8 hard are formed with balls of 4 mm diameter using three different homogeneous coverages 50, 75 and 99 percent. All curvatures emerge in the direction of the impacting balls, which is defined as “concave” curvature and designated by negative values. Obviously the material state of the face sheet has an important impact on the magnitude of deflection and thus on the curvature of the sheet. Within sequences of same material, coverages higher than 75 % does hardly affect the forming result.

DISCUSSION

FE-simulations with low indentation speeds of individual balls show a fundamentally different forming behaviour of sandwich sheets compared to monolithic materials. They show in the case of Hylite distinct radial material flow solely on the upper surface towards the symmetry axis at any indentation depth which can be described as in-plane “shrinkage” of the upper face sheet. However the rest of the cross section undergoes lateral spread. Presuming multiple occurrences of these incidents in a great number of impacts we can pre-estimate that Hylite can only be deformed to concave curvature with respect to the incident balls. The tests with slow, force restricted and time-independent incidents contribute merely to the importance of geometrical influences on local forming and hence on the resulting curvature of the structure. The ball diameter is not as relevant as the material state of the face sheet in terms of the normalized indentation force. The assumption of exclusive incidence of concave curvatures, observed for low indentation speeds, is supported by shot peen forming experiments at high ball speeds, where only concave curvatures are obtained. Results in Fig. 10 for two materials with identical geometric setup, but different material states show again the importance of the yield stress of the face sheets. At the same peening pressures, which correspond to identical ball speeds, the materials show distinct differences regarding the magnitude of curvature. For a time- and cost effective forming process we can state that the coverage should be approx. 75 %.

CONCLUSION AND IMPLICATIONS

Experimental studies in industrial scale as one major subject of this work show the potential of the combination of the Shot Peen Forming process and sandwich-materials. These studies are supplemented by basic experimental indentation tests and their numerical simulations which point out on the importance of geometric and time independent effects, like geometry and - with limitations - material states. Influences of dynamic effects e.g. strain rate sensitivity of the face sheet, potential reversible deflection of the sheet during the impact are neglected. To obtain a closer relation between individual quasistatic indentation incidents and multiple high-speed impacts in the industrial process, additional work has to be done.

Another important field of future research should surely be the analysis of potential damage of the structure during the peening treatment. In this study the main focus is put on the principal applicability of the shot peen forming process to Hylite material.

ACKNOWLEDGEMENTS

The authors of this study would like to thank the Deutsche Forschungsgemeinschaft (DFG) for their financial support within the project HI 790 / 19 “Mechanismen beim Kugelstrahlumformen von Sandwich- und Laminatmaterialien”.

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