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# AME AUSTENITIC SANDWICH MATERIALS IN THE FOCUS OF RESEARCH

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## INTRODUCTION

Society today demands a rising ecological standard for new products which can be roughly described with keywords such as "resource saving", "sustainable" and "recycling". Demands for more economical products go hand in hand with increasing quality requirements. The future developments in mechanical engineering, vehicle and energy system engineering must concentrate on solutions for processes, machines and materials which carefully treat resources and energy and at the same time keep the technical lead with new and innovative products.

Lightweight construction concepts are able to be maintained and operated costs efficiently, reduce production costs, increase the product life for economic reasons reliability of use or optimize the freight of payloads.

Steel has become less favourable in previously dominated areas, e.g. in the automobile industry since lightweight materials such as aluminium and magnesium based alloys as well as synthetic materials and composite materials have gained a broad range of acceptance.

Steels with a higher strength and a higher young modulus than conventional steel cannot quite compensate the advantage of these materials for lightweight construction, despite the advantage of a lower price, a better forming behaviour, a higher strength and the possibility of recycling without problems. A trend-setting solution for a higher demand of steel use seems possible by the development of high-strength, austenitic steels with a large manganese content. These steels show comparable mechanical qualities, and at the same time are more economical and in addition permit lightweight construction. Sandwich systems represent an interdisciplinary concept by a combining the areas of material choice, production engineering, design and function integration for the fulfillment of the high demands on modern materials. The development of these lightweight construction is mainly, among others, the automotive industry. The sandwich material (multilayer composite materials, hybrid material) connects the advantages of miscellaneous materials (e.g. low density, high bend resistance, sound and vibration insulation, energy absorption, high load-capacity at a low weight, need adapted qualities) with each other.

Nowadays these new materials and (lightweight-) designs are appreciated as key technologies for innovative research and development. The further development of the materials, the optimization of material applications and the necessary manufacturing method with reduced costs and time are permanent research objectives.

These new compound systems open new, future-oriented applications. The weight reduction is considerable for this task. A combination of steel/synthetic material/steel has the advantage of a higher strength opposite to a corresponding steel and, depending on the choice of the steel grade, a high corrosion resistance.

These sandwich materials find their way in more and more industrial applications such as automotive-, building-, transport-, chemical-, aerospace- and airplane industry.

## HISTORY OF SANDWICH MATERIALS

The multilayer sandwich material as a construction principle is not new. Thomas von Karmann and Peter Stock patented (Brit. patent No.253/884, July 21, 1924) the application of sandwich materials in the aircraft construction in 1924. The fighter-bomber "De Havilland, i.e. 98 Mosquito" used in the 2nd World War was mostly made of sandwiches with surface layers of plywood and a core of balsa wood (therefore the nickname "wooden wonder").

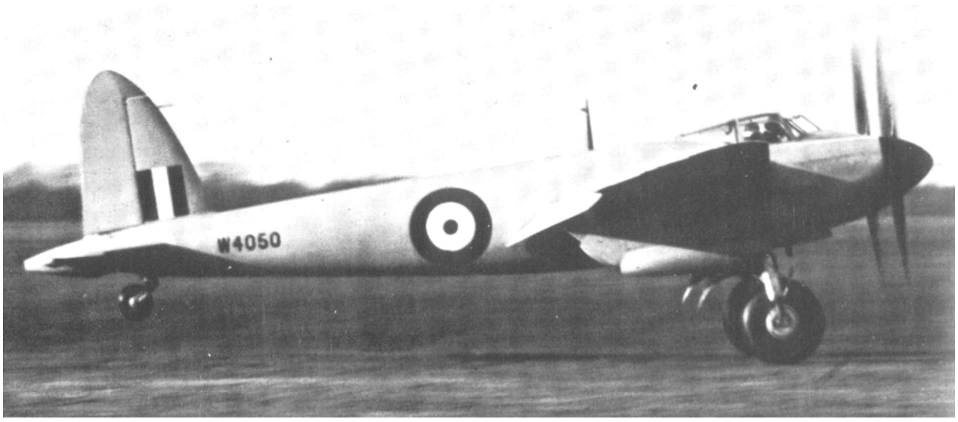


*Fig. 1. De Havilland D.H.98 Mosquito*

The first essays and theoretical based works from to the "sandwich" topic are from this time (1935-1945). Application are found not only in aircraft construction [1] but also in the automobile manufacturing industry, in architecture, in shipbuilding engineering as well as in the sports and leisure industry. Some examples are described in the following.

The aeronautics industries has always been a sapper at the development of new materials and material compounds. The composite layer materials ARALL (Aramid Fibre Reinforced Aluminium Laminates), GLARE (Glass Fibre Reinforced Aluminium Laminates) and CARALL (Carbon Fibre Reinforced Aluminium Laminates) were developed here. Only the first two gained acceptance from the market. These fibre reinforced composites can consist of three (surface layers made of aluminium, 0.2 to 0.5 mm thickness, central layer of fibres with epoxy resin watered in a thickness of 0.125 to 0.5 mm) or more layers [2].

Sandwich sheet metals increasingly find their way into the automobile industry. They are used for car bodies both for of lightweight reasons and for sound reduction. Sandwich materials are used with a homogeneous or inhomogeneous core of foams and other hard materials. Examples of components of sandwich constructions are cowl applications, gear box cover, hoods, car boot cover, oil sumps and chassis frame components. A well known example for the use of sandwich sheet metals in the automobile industry is the lightweight construction bodywork ULSAB (Ultra Light Steel Auto Body). Some of the components, such as spare wheel hollow and cowl application were manufactured of steel sandwich sheets. These components can be executed up to 50% lighter with the same properties concerning geometry and function than with normal deep drawing steel. The material consists of two thin steel sheets which are bonded with a thin polypropylene material layer as core material.

Aluminium polypropylene sandwich sheets called "Hylite" were used for the roof and the hood at a Ford e-Ka, in May 2000. The e-Ka developed in the Ford research centre “Aix-la-chapelle”, offers several lightweight construction elements. The weight of the e-Ka could altogether be reduced by 45 kilograms, especially by the use of aluminium. The roof (weight saving: 5.5 kg) and the hood (5.3 kg) were produce of Hylite, a composite material where two layers of aluminium enclose a layer of polypropylene in a sandwich manner.

## MATERIAL MANUFACTURING

In the current investigation sandwich materials with high-grade steel sheets were researched. They combine a good corrosion behaviour and acid resistance with good damping behaviour and noise reduction. The idea was, to compare different sandwich materials and examining them for their formability. Sandwich materials with metal layers of austenitic steel (0.5 mm thickness) were manufactured for different research projects, supported by the DFG and AiF.

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For the production of the sandwich materials a 0.5 mm thick polyolefin foil was used. This foil product consists of lime, soot and a mixture of PP and PE-Copolymers. Soot and lime serve as a filler to be able to produce the product more economically. Furthermore three other materials were used as core materials. Different granular materials with fibres and a textile hybridroving (Twintex) with a layer of glass fibres in a polypropylene matrix. The core materials are displayed in table 1. They differ in length of fibre, their volume quota and the used matrix material. The investigations should show whether the core materials effects the complete sandwich for example in its forming behaviour.

*Table 1. Core materials used*

| core material | fibre volume quota [%] | fibres | matrix | core |
|---|---|---|---|---|
| PP-GF40 | 40 | long glass fibres | polypropylene (thermoplast) | polymer 1 |
| PA66-GF30 | 30 | short glass fibres | polyamide (thermoplast) | polymer 2 |
| Twintex | 50 | long glass fibres | polypropylene (thermoplast) | polymer 3 |
| PP/PE foil | - | - | polypropylene/polyethylene | polymer 4 |

| | | | | |
|---|---|---|---|---|
| | | | (thermoplast) | |

Table 2 shows the characteristic data of the different used core materials. The big differences in the Young's modulus of the core materials let us expect different formability of the sandwiches. The Twintex shows a max. elongation of only 8%. Because of that, no high formability was to be expected despite the Young's modulus.

*Table 2: Characteristic data of the used core materials*

| | PA66-GF30 | PP-GF40 | TWINTEX |
|---|---|---|---|
| young's modulus [MPa] | 2.500 | 9.100 | 41.800 |
| density ρ [kg/m$^3$] | 1360 | 1220 | - |
| water absorption at ambient temperature [%] | 5,5 | < 0,1 | - |

The first manufacturing method to be tested was a press-joining process. This was performed discontinuously by an 8" and 10" rolling stand (fig. 2). The high-grade steel sheet metals [X2CrNiMo17 12-2 (1.4404) and X6CrNiMoTi17 12-2 (1.4571)] with a thickness of 0.5 mm were first cleaned and degreased. The steel was than coated with a defined layer of adhesive. The used adhesive agent is a conventional product based on epoxy with resin. After activating the adhesive the upper sheet metal was joined with a 0.5 mm thick PP/PE-foil in a rolling process. During the next step the produced upper sandwich was bonded with the lower sheet metal, also by rolling. For durable and reproducible adhesive bonding an activation temperature of the adhesive of 254°C ± 2°C was needed. The necessary dwell time of the coated sheet metals was 30 seconds in a stationary convection oven.

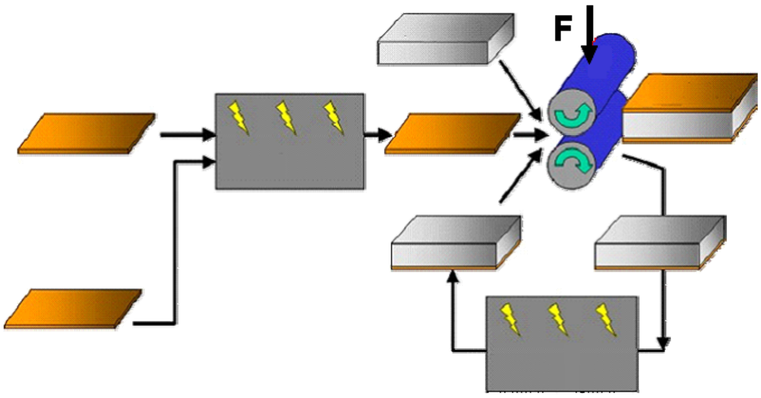



*Fig. 2. Manufacturing in a press-joining process*

The other way to produce sandwich material for these investigations is shown in figure 3. The discontinuous production of this manufacturing method was carried out with a cooling and heating system deduced in a laboratory press system. For the sandwich production a sufficient set of the granular material was mixed with the adhesiv agent. This mixture was inserted as a packed bed between the cleaned and degreased sheet metals. At temperatures between 260 to 300°C the sandwich materials were then pressed for about 60s. To reach an even core layer thickness, the sandwich material was pressurized at 445 kN/mm$^2$. After the press process the sandwich material annealed to room temperature with a cooling rate of 10°C/min. For adjusting the core layer thickness and the thickness of the complete sandwich material a metal frame was used as a spacer.

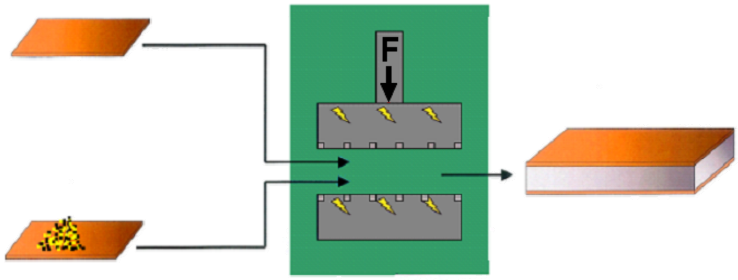



*Fig. 3: Manufacturing in an heating press*

These sandwich materials were examined in different tests for the bond strength of the individual layers and for their forming behaviour. The Erichsen Test [3] was used to investigate the forming behaviour and is explained in the following.

## TESTING OF THE MANUFACTURED AUSTENITIC SANDWICH MATERIALS

The different sandwich materials which were produced were examined for their deep drawing behaviour in different tests, for example in the Erichsen Test. The height of the cup is a reference value to compare different sheet materials.

The Erichsen Test is a cup test in which a piece of sheet metal, restrained except at the center, is deformed by a cone-shaped spherical-end plunger until fracture occurs. The height of the cup in millimeters at fracture is a measure of the ductility.

Table 3 shows the measuring height of the cup (deep drawing index) for materials manufactured in a press-joining process. As sheet metal layers steel 1.4404 and aluminium AlMg3 were used. These materials with a thickness of 1.5 mm show good results in the Erichsen test. Best tested material was the sandwich with steel layers with a cupheight of 20.2 mm.

*Table 3. Maximum height in the Erichsen-Test*

| material | total thickness | sheet metal thickness | deep drawing index |
|---|---|---|---|
| 1.4404 / PP / 1.4404 | 1.5 mm | 0.5 mm | 20.2 mm |
| 1.4404 / PP / AlMg3 | 1.5 mm | 0.5 mm | 19.6 mm |
| AlMg3 / PP / 1.4404 | 1.5 mm | 0.5 mm | 16.7 mm |
| AlMg3 / PP / AlMg3 | 1.5 mm | 0.5 mm | 16.4 mm |

These results compared to the other sandwich materials which are produced in the heating press, showed an interesting finding. Figure 4 shows the results of the Erichsen Test (height of the cup) depending on the core thickness, the manufacturing temperatureand the adhesive agents (H1, H2, H3). The maximum height is reached with the 0.5 mm thickness core material by a production temperature of the Sandwich material at 260°C. No Sandwich system with a granular core material reached the height of a cup of systems with a PP/PE foil as core material. It stands out that no material with a granular core has reached the height of the sandwich material with a foil as a core layer. The difference is up to 7.4 mm.

For a better understanding of the testing materials and the possibility to compare the two different cases of sandwich materials an intensive analysis (figure 5) was necessary. Figure 5 shows the Erichsen tests for the granular materials with a core thickness of 0.5 mm. Sandwich materials with the same over-all thickness and the same core thickness can be compared with each other although they have different core materials.

The maximum for the series of experiments in figure 5 is 12.8 mm for the Polymer 1 with the adhesive agent H3 at a production temperature at 260°C and 12.2 mm for the Polymer 2 with the adhesive agent H3 and a production temperature of 300°C. The Polymer 2 has a higher melting point than the Polymer 1. Through this a good formability was reached at a production temperature of 300°C in connection with the adhesive agent H3. Furthermore the Polymer 1 already reached a very good formability at the production temperature of 260°C in connection with the adhesive agent H3. The Polymer 3 (Twintex) already fails early during the Erichsen Test, because the Twintex material only has a strain of 8 % (manufacturer indications).

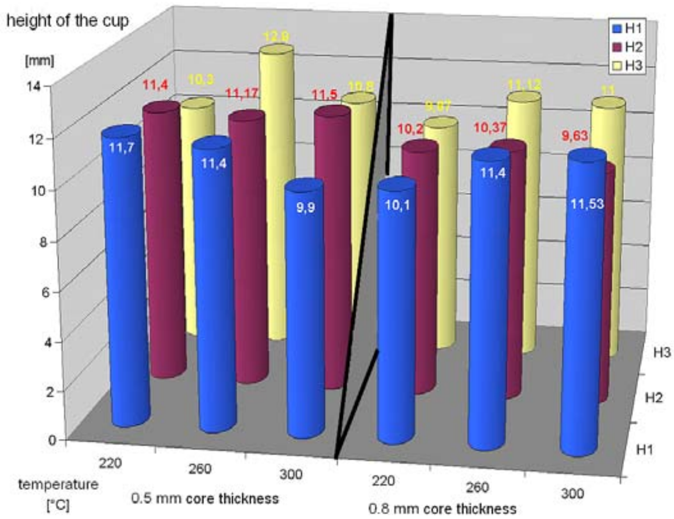



*Fig. 4. Results of Erichsen Test*

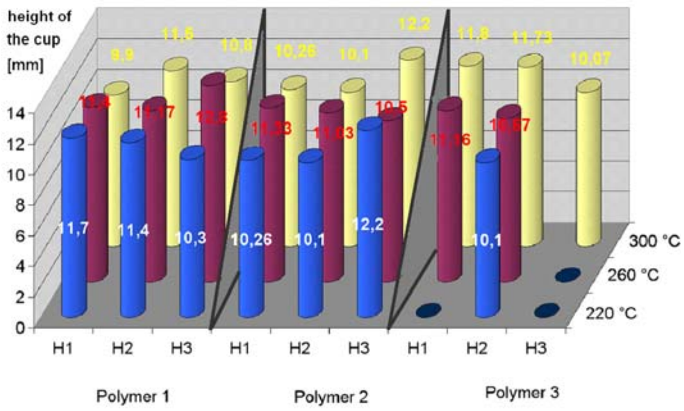


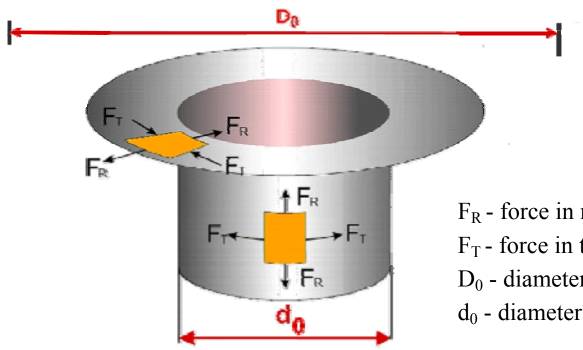

*Fig. 5. Erichsen Test of produced sandwich materials,*
*total thickness 1.5 mm, core thickness 0.5 mm*

**DEEP DRAWING OF AUSTENITIC SANDWICH MATERIALS**

The difficulties in the deep drawing process of sandwich systems dwells from the different behaviour of the used materials, e.g. polymere and high-grade steel. The polymere behaves in a viscous way, the steel in a elastic-plastic way. By the tangential tension ($\sigma_T$) wrinkling in the flange and cup wall fracture can appeare during the deep drawing process [4, 5].

The wrinkling of the metal can be counteracted with blank holders for mono materials. The material is forced into the desired flow direction. With sandwich systems, e.g. metal/PP/PE/metal the metal layer can flow despite a blank holder in the polymers, so that it can come to wrinkling in the metal layer. The higher the resistance of the polymer is brought into line with that of the metal, the bigger the resistance is against wrinkling.

Figure 6 shows a sketch of a deep drawn cup.




$F_R$ - force in radial direction of the cup
$F_T$ - force in tangential direction of the cup
$D_0$ - diameter of the circular blank
$d_0$ - diameter of the punch

*Fig. 6. Deep drawing with blank holder for rotational-symmetric specimen*

For the deep drawing process of sandwich materials the knowledge about the blank holder pressure and -force was necessary. Too little blank holder pressure increases the risk of wrinkling. The blank holder pressure was calculated for steel materials with a thickness of 1 mm by Siebel [4]:

$$p_{BH} = c \cdot \left[ (\beta - 1)^2 + 0,5 \frac{d_0}{100 s_0} \right] \cdot R_m \tag{1}$$

with the parameters: coefficient for steel sheets c = 0,002 ...0,003; maximum drawing ratio ß = 1,98; $d_0$ = 95,2 mm; $R_m$ = 433 MPa and $s_0$ = 1,5 mm. $R_m$ was calculated in the tensile test and ß in the cupping test for the sandwich material produced with layers of steel and a PP/PE foil core. With equation (1) the blank holder force $F_{BH}$ is calculated in equation (2).

$$F_{BH} = A_N \cdot \frac{R_m}{400} \cdot \left[ (\beta - 1)^2 + \frac{d_0}{200 \cdot s_0} \right] \tag{2}$$

For the deep drawing investigations a calculated blank holder force of $F_{BH}$ = 83.029 kN is used. In the following investigations at a deep drawing press the tests with the calculated force show good results as you can see in figure 7.

With $k_{fm}$- mean flow stress and the circular blank of $D_0$ = 225 mm the maximum drawing force is calculated in equation (3).

$$F_{max} = \pi \cdot (d_0 + s_0) \cdot s_0 \cdot \left[ 1,1 \cdot \frac{k_{fm}}{\eta} \left( \ln \left( \frac{D_0}{d_0} \right) - 0,25 \right) \right] \tag{3}$$

The maximum reached drawing force is $F_{max}$ = 190,548 kN. With this data the drawing tension was calculated with equation (4) and the cup wall cross sectional area ($A_Z$) to:

$$\sigma_Z = \frac{F_{max}}{A_Z} = 631{,}804\ MPa \tag{4}$$

Some results of the investigations at a 2.500 kN deep drawing press are given in table 4.

*Table 4. Depth of draw for different sandwich materials*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| sheet layer, lower | AlMg3 | AlMg3 | AlMg3 | 1.4404 | 1.4404 | 1.4301 | 1.4571 |
| sheet layer, upper | AlMg3 | AlMg3 | 1.4404 | 1.4404 | 1.4404 | 1.4301 | 1.4571 |
| depth of draw [mm] | 61,06 | 66,85 | 70,04 | 68 | 73,95 | 65,7 | 67 |
| | | | | | | | |
| sheet layer, lower | AlMg3 | AlMg3 | AlMg3 | 1.4404 | 1.4301 | 1.4571 | 1.4571 |
| sheet layer, upper | 1.4404 | AlMg3 | 1.4404 | 1.4404 | 1.4301 | 1.4571 | 1.4571 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| depth of draw [mm] | 68,5 | 63,35 | 62,9 | 66,5 | 66,6 | 59,2 | 65,9 |
| | | | | | | | |
| 1mm sheet of 1.4301 | 68,5 | - | - | - | - | - | - |

The sandwich materials in table 4 with high-grade steel sheets as lower and upper layers reached the greatest depths approx. to 74 mm without wrinkling and a cup raise fracture. If aluminium was used as one layer (upper layer of the cup) wrinkling at the cup wall appeared. With a higher blank holder pressure the wrinkling could be eliminated. But in further test only a depth of this material of 66.85 mm was reached. The sandwich materials obtained without exception good results.

Figure 7 shows a simple quadratic geometry with austenitic steel layer on both sides of the cup. This cup reached a depth of 73.95 mm with the parameters: diameter of the circular blank $D_0$ = 225 mm, blank holder pressure $p_{BH}$ = 83 kN, punch corner radius $r_C$ = 25 mm, punch border radius $r_B$ = 25 mm, drawing ring radius $r_R$ = 25 mm. The quadratitic geometry has a length of 100 mm.

*Fig. 7. Cup with layers of austenitic steel (1.4404) and a PP/PE-foil core*

**SUMMARY**

If some years ago sandwich systems were used only in individual sections, then they will find the way to more and more industry areas today. By the combination of construction and material they offer the substitution of classic mono materials, because next to lightweight construction they offer quantities like anti-corrosion protection and damping [6, 7, 8].

The development of new materials and technologies still stands at the beginning. New adapted material systems like natural fibre composites, hybrid structures of metals, polymers and ceramics increasingly gain meaning in future. The development for adapted composites, the processing of a material construction matrix for composite materials as well as the improvement on the adhesion and cohesion qualities by shift transitions graduated are future design objectives. Furthermore at the beginning of the material design process the aspects of the environmental protection and recycling have to consider.

Tool concepts and procedures should also be reconsidered for the component production from sandwich materials or be developed newly or adapted to the materials.

Aspects of the environmental protection and recycling are getting more important in these considerations from the beginning of the development on. The use of natural fibres can serve as reinforcements in a matrix material between two sheet metal sheets as an approach.

The interest in research and development in the area of these new materials has increased strongly during the last few years. In combination with other fields of research, like the nanotechnology, the biotronik, the mechatronics and the material development, the sandwich materials offer a large and important spectrum for the future.

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