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Highlights of designing with Hylite – a new material concept

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Abstract

Starting with a general analysis of the requirements for a successful introduction of new materials, this paper addresses the question of accelerating the industrial adoption of Hylite – a new aluminium–plastic–aluminium laminate material. Despite of the commercial introduction a decade ago the material is not really familiar to engineers and therefore in this paper an attempt is made to fill the information vacuum by providing guidelines on designing with Hylite which are critical to its market success and by demonstrating its established applications, thus sharing the experience in working with the material.

Keywords: Laminates; Forming; Selection for material properties

1. Introduction

There is a generally recognized discrepancy between our excellence in science and technology and our relative inefficiency in exploiting them to our economic advantage [1]. In most cases, having been developed and tested, a new material can still be many steps away from being utilized in end products. Often there is a lengthy incubation stage between the discovery of a new material and its full exploitation in the market and this period can be more than 10 years.There is plenty of space to learn from the experience of the design community in exploiting new materials.

The curve of industrial adoption is typical of almost all the materials developed and schematically it can be represented by the graph in Fig. 1 [2]. The figure shows that as soon as the research activities are started they are accelerated by the scientific curiosity and over-optimistic forecasts of the material's impact on global economic development [2].

The amount of research activities decreases after about 10 years. Safe, economic and broad use of a new material requires a high level of understanding on the part of a designer why a new material behaves as it does. Potential users may discover that information relating to specific properties is scarcely available and there is a list of potential problems to consider before exploiting a new material. If potential problems are not foreseen by developers of a new material this will lead to loss of interest in utilizing it and eventually to the observed decline in development activities. The potential problems that a targeted user can face are briefly explained below [3].

1.1. Long-term availability

There should be a standard range of available material in terms of properties, geometry, finishing, etc. A material has to be produced in large quantities over a

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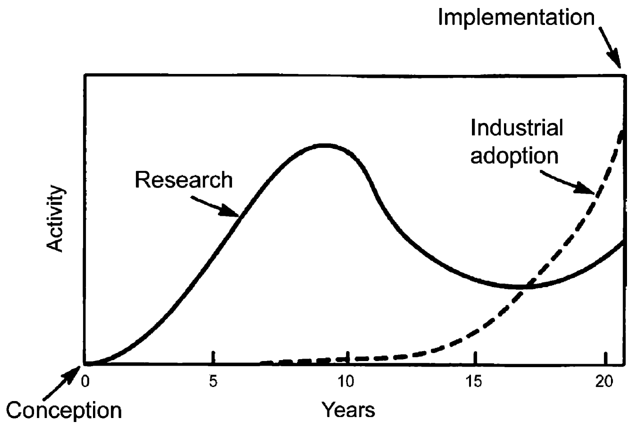

Fig. 1. Schematic of development history for new construction materials [2].

long period of time through sensible commercial processes. At the same time, it has to be made clear that the material manufacturing process is stable enough to produce the advertised range of material properties.

1.2. Costs

It is likely that the cost of a new material can be very high in comparison with conventional materials. Therefore, it has to be shown that an overall reduction in product cost is possible because of an unusual combination of properties or due to cheaper processing-assembling methods.

1.3. General data

Materials react differently to their service environment, therefore a new material must not deteriorate, corrode or be altered in such a way that the functions of the product are impaired. Information relating to the behaviour of a new material under important specific service conditions has to be easily available. Ideally, its properties should be accurately known and its advantages over existing commercial materials clearly highlighted.

1.4. Design methods

New materials offer new solutions to engineering problems and encourage the re-design of existing solutions. However, it is important that conventional methods and approaches to designing with established materials are applied with caution. Otherwise it could be unsafe or at least less cost effective.

1.5. Processing

The problems with adoption of a new material and with utilizing it in certain applications can spring from the lack of satisfactory manufacturing techniques. The fabrication processes have to be carefully optimized because of the inevitable sensitivity of material properties to microstructures controlled by processing conditions and interactions. It has to be shown that efforts are being made for developing, testing and optimizing the fabrication techniques.

1.6. Recycling

There can be serious problems related to a new material's disposal or recycling that will have to be anticipated while developing a successful application.

Returning to the curve of industrial adoption (Fig. 1) one may state the following. Only when a material shows its entire potential in some successful applications the market demand grows, pulling and expanding back the research and development activities. Thus, for example, the developments in the field of injection moulding technology opened new opportunities for thermoplastic composites in the production of engine intake manifolds. Lower cost, ability to produce complex manifold design in one moulding operation, improved engine performance and 30–50% weight savings made reinforced polymers very attractive for car manufacturers [4]. The successful application can lead to a widespread reappraisal of the potential of a new material and to a reassessment of its likely advantages over other commercially available materials.

A vast majority of product design innovations are improvements of existing concepts. Therefore the strongest possibilities for broad utilization of a new material lie with substitution of existing commercially available materials with similar property profiles in their established applications. A new material must show that product attributes are either improved or at least not affected by the material replacement with a decrease in final cost. If a new material adds value without an increase in a product's manufacturing cost it is very likely that it will successfully enter the market [5].

In the mid-1980s the material producers, encouraged by the car manufacturers, returned to the concept of a sheet material with the most efficient structural shape in bending that can be used for producing the outer panels of a car and can give significant weight reduction. This basic concept of obtaining stiff and lightweight laminate material by using strong facings spaced by a low-density material in between was discovered in the 19th century but did not receive extensive practical use mainly due to the lack of reliable adhesives needed to bond the facings to the core. Various material research activities were started that were focused on substituting steel or aluminium in car outer panels with new lightweight laminate materials while keeping the strength, stiffness, impact resistance and other properties on the same standard level.

The development of Hylite – a lightweight sandwich sheet, which consists of two thin aluminium layers with a thermoplastic polymer in between was a part of the afore-mentioned research. Different concepts of Hylite were evaluated with regard to its feasibility and properties. After excessive testing it became clear that the material had reached the required level of maturity to be used for manufacturing products in various markets such as automotive, transportation, consumer goods and construction [6].

This paper can make a significant contribution to the efforts of achieving faster industrial adoption of Hylite. It provides design engineers with knowledge and experience in designing with this material, thus encouraging them to explore new possibilities for the application of Hylite. Section 2 presents the characteristics of Hylite in a way that facilitates its comparison with other materials. An overview of the properties and combination of properties is given. Section 3 summarizes the guidelines for designing with Hylite and finally Section 4 presents case studies illustrating successful and potential applications of the material.

2. Hylite compared with other materials

As explained before Hylite is an aluminium–plastic–aluminium laminate. As a core material polypropylene is used and the following aluminium outer skins are possible: AA 5182 (soft) for applications such as the deep drawing of body panels; AA 5182-H18 (hard) for applications such as flat panels.

The characteristics of Hylite presented here are organized in a way that facilitates making the decision whether the material can be used for a certain application or not [7]. For this purpose, design-limiting material attributes are clarified first.

2.1. Low weight and flexural rigidity

Hylite was developed primarily to replace sheet steel or aluminium in applications where flexural rigidity is the design constraining criterion. Therefore, it is designed to have lower weight per unit area to replace existing materials while exhibiting equivalent rigidity. Table 1 compares steel and aluminium sheets with 1.2/0.8 Hylite on the basis of equal flexural stiffness. As can be seen from this table Hylite is 65% lighter than steel sheet and approximately 30% lighter than aluminium sheet.

Table 1
Weight comparison of Hylite with steel and aluminium at a constant flexural rigidity

	Steel	Aluminium	1.2/0.8 Hylite
Thickness, mm	0.74	1.08	0.2/0.8/0.2
Specific weight, kg/m^2	5.8	2.9	1.82
Maximum elongation, %	30–40	20–25	18–20

2.2. Operational temperatures

The stiffness of a metal–plastic laminate is affected only by the volume fraction of the polypropylene core and hardly by its properties. This can be assumed only if the polypropylene core can maintain its thickness. At the temperatures close to the softening point of polypropylene it can no longer withstand the stress and starts to deform and the rigidity of a laminate drops sharply. Properties of polypropylene are also influenced by low temperatures. The lower limit of operating temperatures is about -30 °C.

2.3. Corrosion resistance

The resistance of Hylite to corrosion was measured by means of two available methods: Corus Cyclic Test (CCT) and the well-known Salt Spray Test (SST). After SST corrosion test no deterioration could be observed in the aluminium–plastic sandwich. At the same time, after the CCT test had been performed, only slight pit corrosion could be observed in Hylite and no perforation appeared. It is important to mention that the adhesion between the aluminium and the polypropylene was not affected.

2.4. Sound comfort

Tapping Hylite panel produces a less 'metallic' sound compared to a steel or aluminium sheet. The experiments were performed to compare the contact noise produced by tapping steel and Hylite panels. They revealed that the sound intensity in case of a Hylite panel was 3.4 dB lower. Adding damping material to the steel panel gave the same intensity of sound. Therefore, using Hylite for outer panels can eliminate the necessity to employ damping materials that add to weight and cost.

Next, some property charts will be shown: bending modulus against density; Young's modulus against strength. They give an overview of the most advantageous properties of Hylite and enable selection through the use of material indices.

2.5. Light and stiff panel

The best materials for a light and stiff panel are those with the large values of the material index M_b, [7]:

$$M_b = \frac{E^{1/3}}{\rho}, \tag{1}$$

where E is the modulus of elasticity of a material and ρ is the material density.

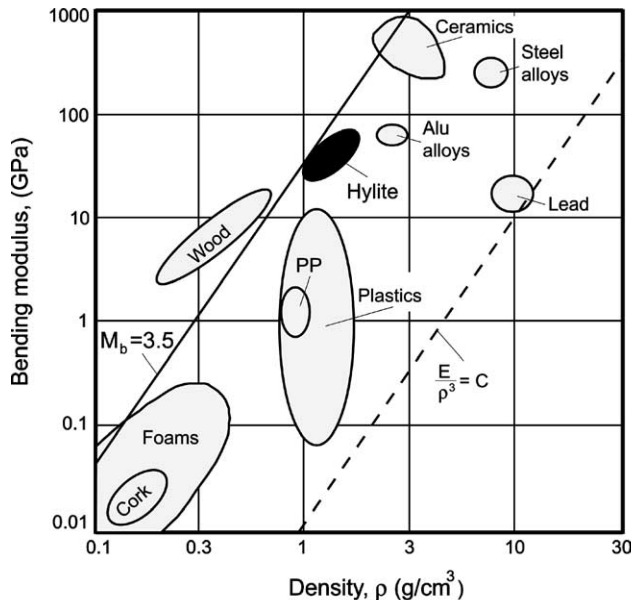

Fig. 2. Bending modulus plotted against density for lightweight, high stiffness design [8].

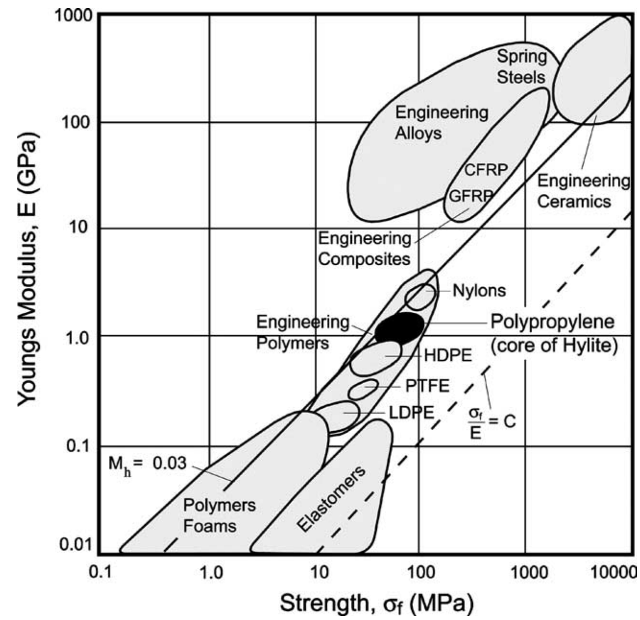

Fig. 4. Materials for elastic hinges [7].

A bending modulus vs. density property plot is shown in Fig. 2. In the chart, the best materials for a minimum weight and deflection limited design lie top left. The selection line for the material index M_b has a slope of 3. The line is positioned so that a small group of materials with the largest values of M_b is left above it. This plot shows explicitly that Hylite combines excellent flexural rigidity with a low weight [8].

2.6. Elastic hinge

Locally removing the aluminium skins of Hylite gives an elastic hinge integrated into the sandwich sheet (Fig. 3). The property chart in Fig. 4 compares polypropylene with other materials that are used for elastic hinges.

The material that can be bent to the smallest radius without yielding or failing is the best material for the elastic hinge. That is, the one with the greatest value of the index M_h [7]:

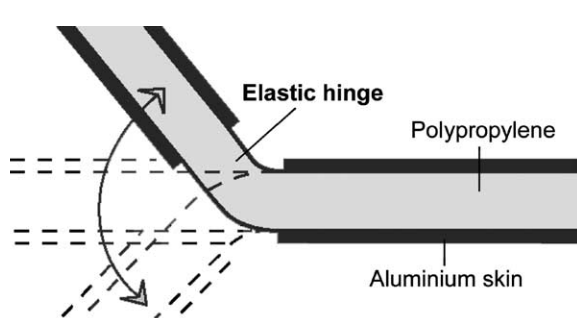

Fig. 3. Elastic hinge of Hylite.

$$M_h = \frac{\sigma_f}{E}, \quad (2)$$

where σ_f is the failure strength.

The plot is shown in Fig. 4. In this chart, the candidates for the best elastic hinge lie bottom right. The selection line for index M_h has a slope of 1. This line is positioned in such a way that a small group of the materials with the largest value of the index M_h is left below. As can be seen from the plot the best choices for the elastic hinge are all polymeric materials.

Cheap products with an elastic hinge are generally moulded from polyethylene, polypropylene or nylon. All these materials together with elastomers are very good for making an elastic hinge but they may not be rigid enough to meet other design needs [7].

Made of polypropylene the elastic hinge of Hylite is highly flexible and has a large number of loading cycles to fatigue failure. In comparison with polymers or elastomers Hylite gives higher rigidity of outer parts of products due to its much higher modulus of elasticity. In comparison with metals the integrated hinge of Hylite gives lots of design freedom. Thus, for example, the elastic hinge helps to reduce the box, hinge and lid (three components plus the fasteners needed to join them) to a single box, inclusive elastic hinge and lid, made of one sheet.

3. Guidelines for designing with Hylite

The formulae and explanations presented here can help design engineers to make a well-founded choice of the most suitable geometrical parameters and properties of Hylite depending on the application specific requirements. This is followed by guidelines for the processing, joining, finishing and recycling of Hylite.

3.1. Designing for equal stiffness

For a typical metal–plastic laminate the flexural stiffness, S, is represented by the following expression:

$$S = \frac{b}{12}\left[E_f(t_l^3 - t_c^3) + E_c t_c^3\right], \tag{3}$$

where E_f is the modulus of elasticity of face material; E_c is the modulus of elasticity of core material; b is the width of the laminate; t_l is the total thickness of the laminate and t_c is the thickness of core material.

Following equation is used to determine the specific weight, G, of the laminate:

$$G = (\rho_f \cdot (t_l - t_c) + \rho_c t_c), \tag{4}$$

where ρ_f is the density of face material and ρ_c is the density of core material.

The stiffness to weight ratio of an aluminium–plastic laminate is its most attractive property when considering the replacement of steel or other materials with a laminate to achieve weight reduction. On dividing the flexural rigidity S of a sandwich by its specific weight G the stiffness to weight ratio or specific rigidity, D, of the laminate can be obtained. It is expressed as follows:

$$D = \frac{S}{G} = \frac{b t_l^2 E_f}{12\rho_f} \cdot \frac{1 - \left(1 - \frac{E_c}{E_f}\right) \cdot \frac{t_c^3}{t_l^3}}{1 - \left(1 - \frac{\rho_c}{\rho_f}\right) \cdot \frac{t_c}{t_l}} \tag{5}$$

If the thickness of Hylite is a constant then by varying the core volume ratio, t_c/t_l, it is possible to construct a sandwich with a maximum specific rigidity. This dependency is shown in Fig. 5.

This figure shows that the maximum specific rigidity is achieved when the core volume ratio is approximately 0.5. The specific weight of Hylite for a given flexural rigidity is minimal when the value of t_c/t_l is 0.81.

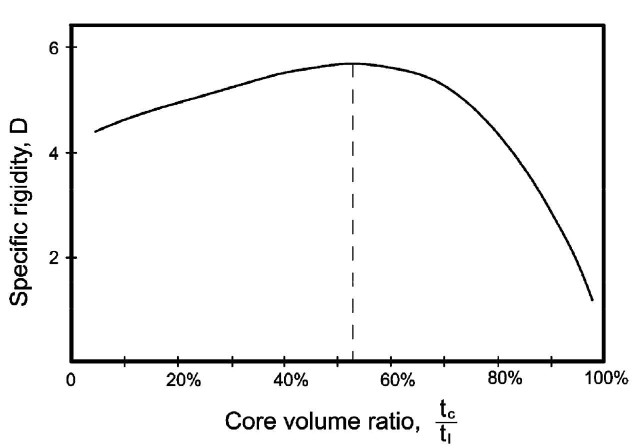

Fig. 5. Maximizing the specific rigidity of Hylite by varying the core volume ratio.

We can now provide a general equation to help design engineers to determine the total thickness of Hylite, t_l, required to match the rigidity of a steel (or aluminium) plate with thickness t_o:

$$t_l = t_f + \sqrt{\frac{E_o}{E_f} \cdot \frac{t_o^3}{6t_f} - \frac{t_f^2}{3}}, \tag{6}$$

where t_f is the thickness of face material; E_0 is the modulus of elasticity of original material and t_o is the thickness of original material.

3.2. Designing for equal dent resistance

Dent resistance is an important characteristic for any thin material especially if it is to be used in a visible outer panel where dents are unacceptable. Dent resistance, D_p, is the energy required to produce a dent of a specified depth. It is expressed as follows [9]:

$$D_p \approx \frac{(\sigma_y t^2)^2}{S_p}, \tag{7}$$

where σ_y is the material yield strength; S_p is the panel stiffness (for automotive panels it is defined as $S_p \sim Et^2$); t is the panel thickness.

Panel dent resistance depends on the yield strength and strain-rate sensitivity of the material and on panel stiffness. Dent resistance generally increases with increasing yield strength, and decreases with increasing panel stiffness. The dent depth, h, obtained can be expressed as a function of the denting energy [9]:

$$\frac{1}{h} \approx D_p^{0.5} \approx \frac{\sigma_y t}{(E)^{0.5}}. \tag{8}$$

Several laminates were tested to identify the influence of the core volume ratio, t_c/t_l, on the dent resistance. Fig. 6 compares the dynamic dent resistance of Hylite and some aluminium–plastic laminates that have thinner cores and thick skins.

As can be seen in this figure the influence of the total metal thickness is large. The aluminium–plastic laminates tested, in spite of having approximately the same total thickness, have a lower dent depth at higher impact energies compared to Hylite. At low impact energies the dynamic dent resistance is almost equal.

Eq. 8 allows the comparison of the dent resistances of metal–plastic laminates of different compositions with solid materials on an equivalent weight basis. For the dent resistance of Hylite to be equal to the dent resistance of steel or aluminium sheet it is necessary that [9]:

$$\frac{t_l}{t_o} = \frac{\sigma_{yo}}{\sigma_{yl}} \left(\frac{E_f}{E_o}\right)^{0.5}, \tag{9}$$

where σ_{yo} is the yield strength of original material and σ_{yl} is the yield strength of a laminate.

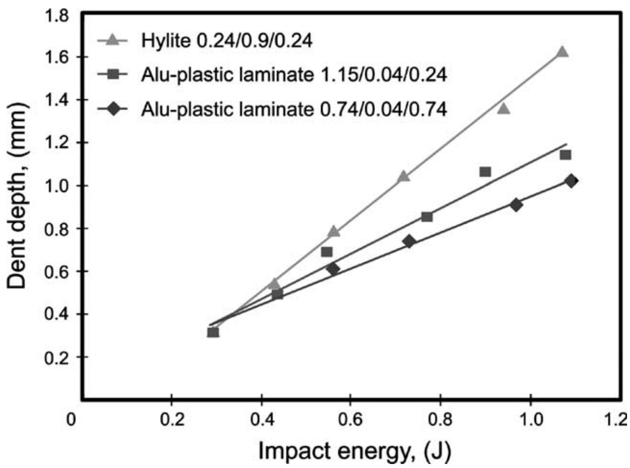

Fig. 6. Dynamic dent resistance of some aluminium plastic laminates.

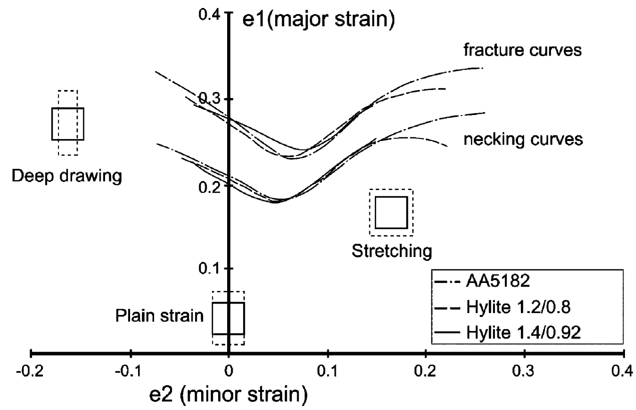

Fig. 7. FLD of Hylite (different thicknesses) and aluminium alloy.

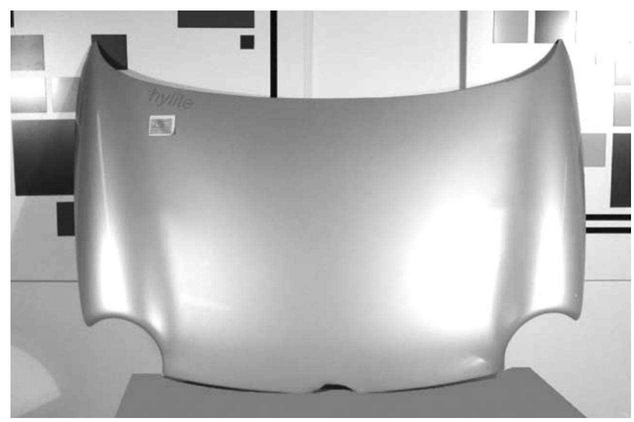

Fig. 8. Bonnet of VW Lupo made of Hylite.

Noting that the polypropylene core does not contribute significantly to the tensile properties, the yield strength of Hylite can be expressed by the following equation [9]:

$$\sigma_{\mathrm{yl}} = \frac{2t_{\mathrm{f}}}{t_{\mathrm{l}}}\sigma_{\mathrm{yf}}, \tag{10}$$

where σ_{yf} is the yield strength of face material.

The dent shape measurements revealed that the dent in a steel–plastic laminate is more local in comparison with an aluminium–plastic laminate and therefore better visible. That is why, for applications where preserved visual appearance is a design constraint, the laminate with aluminium facings is preferred.

3.3. Designing for manufacturing and assembly

3.3.1. Forming of Hylite

Typical sheet metal forming methods like drawing, bending, shear cutting, punching and bead forming can be used as shape creating processes. The forming characteristics of laminates are not quite the same as those of steel and vary with the properties of the face sheets, the core volume ratio and to a lesser extent with the characteristics of the core. Normally material forming capabilities are limited by the occurrence of local necking, fractures or wrinkles, etc. Therefore the forming limit diagram (FLD) of Hylite can be used to predict to what extent the material can be formed by deep drawing or stretch forming or by combinations of the methods. The FLD of Hylite is shown in Fig. 7.

For the assessment of the FLDs two types of Hylite were used: 1.2/0.8 Hylite 6.6.6 and 1.4/0.9 Hylite 6.6.6. For a comparison the FLD of aluminium alloy AA5182 was determined. Knowing the limitations of formability of Hylite is important when making the parts or designing new products in which the advantages of the material can be utilized without exceeding its limits.

For a new material to supersede the existing commercially available materials in certain applications it is very important that the production process does not have to be changed substantially. For automotive applications the drawing process of Hylite sheet is comparable to that of aluminium and steel sheets. To asses the suitability of Hylite for the mass production of automotive body outer panels a pre-validation project involving deep drawing and flanging of a bonnet of a car was carried out. During the project the main focus was on production cycle time, quality and cost. The pre-validation of Hylite was successfully performed on the basis of 500 bonnets (Fig. 8).

The complicated component of a car was produced using industrial equipment with minor modifications of the standard tooling and production sequence. The reproducible procedure of deep drawing and flanging of Hylite requires the same number of steps as for steel or aluminium and is accomplished within approximately the same cycle time.

For deep drawing of Hylite some minor changes to the tooling may be necessary to adjust to the specific process parameters. The following technical details must be taken into account:

- The drawing and blank-holder forces, and consequently the tooling wear, are considerably less than for steel and aluminium drawing.

- When bending Hylite the minimum radius of the tooling has to be considered. Very sharp radii can cause rupture of the aluminium skins. When smaller radii are needed, for instance for making the hem on the edge of Hylite specially developed techniques, such as "hot bending" and "hot ribbing" can be applied.
- Aluminium laminates can be formed at temperatures that soften the core material and allow independent motion of the skins.
- In shear cutting the clearance must be approximately 4% of the thickness of Hylite.

3.3.2. Machining

Various machining methods can be applied for processing Hylite: saw cutting, water-jet cutting, drilling, milling. Some process parameters have to be considered:

- The vertical speed must be lower when drilling Hylite. Cutting speeds are the same as for aluminium.
- Removing aluminium outer skins by milling creates an elastic hinge. Milling parameters have to be adjusted to make the edges of the groove sharp.
- Various sizes and shapes of mills can be used for producing elastic hinges or for making flanges with sharp angles.

3.3.3. Joining and finishing

Different existing methods can be used for joining Hylite, such as mechanical fastening or structural adhesive bonding. Most of the traditional mechanical fastening methods for sheet steel can also be used with metal-plastic laminates. These include threaded fasteners, rivets, staples, stakes, spring fasteners and clinching. Experiments have proved that in case of self-piercing rivets and blind rivets heat-treatment (approximation of the coating procedure for outer car panels) has a slightly negative effect on the tensile strength of the joint.

Adhesives allow simple and effective attachment. The main advantage of adhesive bonding over other fastening techniques is that adhesive joints usually employ relatively large contact areas in comparison with other fastening techniques. The distributed loads are compatible with the strength of the thin laminate skin. Similar adhesives as for aluminium sheets may be used. The durability of adhesive bonding of Hylite was studied by conducting experiments on sets of specimens. Tests were performed in accordance with car manufacturer's standards. The adhesive bonded specimens were exposed to a hostile environment and at intervals the strength of the adhesive joint was measured. Several alternative adhesives were tested to identify the most suitable one.

Combination of attractive properties of different classes of materials allows less common joining techniques, especially for non-critical applications where the applied stresses are small. For instance the polypropylene core of Hylite can be used to "plug" specially made fasteners into it. Another example is melting the polypropylene core of Hylite together with a thermoplastic "connecting" layer of a part to be attached to the Hylite part. In this way a simple and relatively durable joint can be created.

3.3.4. Recycling

There are commercial processes for the recycling of Hylite. An interesting process involves the separation of the polypropylene from the aluminium skins by means of a hammer mill after the material has been cooled in liquid nitrogen. In this way both the thermoplast and the metal fraction can be used again.

4. Applications of Hylite

Hylite is already being applied in several profitable applications. The material has been introduced into the automotive market. Besides bonnets there are some other automotive parts that can be successfully made from Hylite. The best examples are top floor panels in the new Audi A2 and new roof designs in concept cars. As a material for aircraft containers Hylite brings low weight and high rigidity which are important for this market.

The material was certified for all applications in railway carriages. Typical lightweight applications are skin plates for doors and inside roof cladding. Hylite is utilized in shipbuilding to reduce the weight of high-speed vessels. Existing applications in this market are interior cladding and honeycomb floor panels with skins made of Hylite. The attractive combination of lightness, high stiffness and elastic hinge allows the creation of durable portfolios, folders, diaries and multifunctional cases. Several established and potential applications are described in detail below, representing clearly why Hylite was selected and giving an idea of the possibilities for its further exploitation.

4.1. Lightweight aluminium X-ray film cassette: medical applications

Eastman Kodak Company is the world's largest manufacturer of photographic and diagnostic imaging X-ray films and film holders known as cassettes. The company recently introduced a new X-Ray cassette replacing the one with panels made of solid aluminium. In the new cassette the top and bottom parts are made of 2.0/1.6 Hylite 4.6.4 and this replacement allowed several improvements:

- Utilization of Hylite as a lightweight casing made it possible to reduce the weight of the X-ray cassette by 27% without having to sacrifice other quality characteristics, such as strength and durability. The weight reduction offered considerable improvements of the working conditions of the X-ray staff.
- As a panel material of the new cassette Hylite offers a reduction of the intensity of X-ray exposure to the patient needed for any of the X-ray examinations. This became possible due to replacing the solid material of cover panels with a sandwich consisting of two 0.2mm aluminium skins and an X-ray transparent polypropylene layer.
- The durable elastic hinge and good formability of Hylite gave other important advantages such as ease of handling and the guarantee of an extremely close contact between the sheet of film and the X-ray intensifying screens. The latter aspect helps in producing sharper X-ray images that can make the diagnosis easier.

Various different film cassette sizes are produced from standard Hylite sheet. After applying a polycarbonate plastic covering on the outer surfaces and cutting the standard sheet to the appropriate size the correct shape is obtained in a specially developed thermoforming process. The carefree durable and lightweight cassette for X-ray film leads to a quicker and more accurate diagnosis with less exposure for the patient.

4.2. Outer panels of Alleweder velomobile

The Alleweder is a fully enclosed recumbent tricycle or velomobile that was developed in the early 1990s by the Belgian Bart Verhees. The rider sits inside the completely enclosed vehicle and is protected from rain and cold weather. In addition, the aerodynamic design of the body results in reduced air resistance compared to an open recumbent bicycle or tricycle. The body itself is the load carrying structure, which keeps the total weight of the vehicle low in comparison with a design with an inner frame supporting an external, non-structural enclosure. There are several models of the vehicle with bodies made of aluminium sheets and glass fibre reinforced polymer. The velomobile made of aluminium has certain shortcomings. The high noise level inside the vehicle due to the poor noise-damping properties of the construction material reduces the comfort of the rider and especially disturbs the awareness of outside sounds that are related to the traffic situation. Another aspect is the weight of the velomobile that is relatively high for a human powered vehicle.

To overcome all the shortcomings a velomobile with a Hylite body was built (Fig. 9) and subjected to intensive testing that revealed the following characteristics:

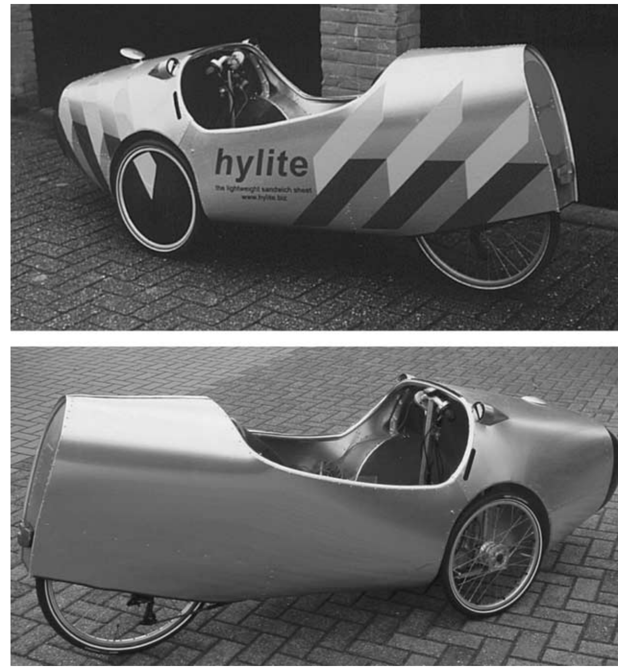

Fig. 9. H-Alleweder Velomobile with body made of Hylite.

- Replacing aluminium with Hylite as the main construction material of the body slightly decreased the weight of the vehicle. However even greater weight benefits can be achieved by adapting the body design to exploit properly the attributes of Hylite and by utilizing some advanced processing and joining techniques.
- The noise measurements show a clear improvement over the aluminium version of the vehicle, especially in the high frequency range due to the contact sound deadening capacity of Hylite.
- The mechanical joints of the velomobile performed well and without deterioration after being tested for their durability under heavy force, vibration, temperature and corrosion conditions.
- The outer appearance, in terms of shape and surface finish, was improved due to the utilization of Hylite.
- High dent resistance and less visible dents can maintain the appearance of the vehicle after having been intensively used.

The velomobile was designed to be a human powered and therefore environmentally friendly means of transport for the medium and long range cycling distances.

4.3. Advanced joining with hylite: bicycle mudguard

Curana is a known supplier of the European bicycle industry. The company developed an improved mudguard (Fig. 10) in which the strength of metal was combined with the broad design possibilities of plastics. The

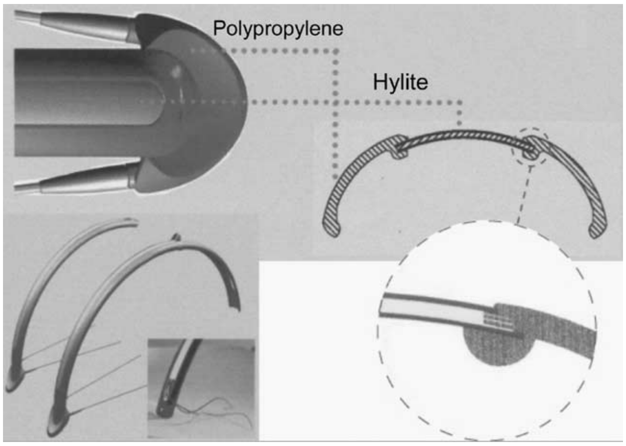

Fig. 10. The innovative bicycle mudguard.

mudguard consists of two parts: a central part made of Hylite provides the required strength and rigidity and the plastic part is used to absorb the vibrations and to bring the required aesthetic appearance.

During the manufacturing process the properly cut and bent Hylite part is placed inside the injection mold. A small part of the aluminium skin is removed off its edges beforehand to expose the polypropylene core. The polypropylene used to create the final shape is injected into the mold and melted with the exposed core of Hylite, thus obtaining a durable and very simple joint. Innovative utilization of Hylite gave following advantages:

- The designed mudguard is 25% lighter than the one fully made of plastic. At the same time its strength and rigidity are at the required standard level.
- The existing manufacturing process does not have to be modified drastically and the joint produced is strong enough to be used without any additional fixation.
- The aluminium skins of Hylite are used as conductors of electricity for the lighting.

5. Conclusions

In this paper, an attempt was made to make design engineers more aware of the benefits of a new aluminium–plastic laminate – Hylite. The paper contains explicit information on the characteristics of Hylite, its processing methods, existing and promising applications, providing designers and engineers with application specific information on Hylite. This may encourage them to look at this new material from different perspectives and can highlight new fields of opportunities for its successful application.

New materials have always been seen as one of the prime movers of future growth and prosperity and a major cause of the revolutionary changes in the world around us. Exciting developments in this area will continue to appear and this will challenge our ability to exploit them to our economic advantage [10].

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References

[1] Young R. New Materials: fact or fantasy?. Mater World 1996;5(12):669–701.
[2] Ashby MF, Evans AG, Fleck NA, Gibson LJ, Hutchinson JW, Wadley HNG. Metal foams: a design guide. UK: Butterworth-Heinemann; 2000. . 1–5.
[3] Cole GS, Sherman AM. Lightweight materials for automotive application. Mater Character 1995;35(1):3–9.
[4] Ulrich KT, Eppinger SD. Product design and development. second ed.. McGraw-Hill; 2000. . 236–260.
[5] Maine EMA, Ashby MF. An investment methodology for materials. Mater Des 2002;23(3):297–306.
[6] Marchal P, Boesenkool R. A case study on materials development at Hoogovens. DOGMA Press; 1999. . 10–16.
[7] Ashby MF. Materials selection in mechanical design. second ed.. Butterworth-Heinemann; 1999. . 116–119.
[8] Boesenkool R, Hurkmans A. The development of a lightweight deep-drawable steel-plastic-steel sandwich. In: Proceedings of EUROMAT 97, 5th european conference on advanced materials and processes and applications. Maastricht; 1997. p. 53–57.
[9] Kaiser R. Technology assessment of automotive applications of metal-plastic laminates, vol. II. Corporate-Tech Planning, Inc. Report prepared for US Department of Transportation; 1980. p. 112–123.
[10] Beukers A, van Hinte E. Lightness: the inevitable renaissance of minimum energy structures. 010 Publishers; 2001. p. 7–15.