Composite Sandwich Panel Manufacturing Concepts for a Lightweight Vehicle Chassis

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ABSTRACT

This paper presents an alternative concept for the production of a lightweight vehicle chassis, using preformed flat panels assembled into a primary structure by the simple processes of CNC routing, folding and adhesive bonding. Minimal tooling and a fully CAD integrated, software driven process provide considerable advantages in prototype development and series production: modifications can be made to software rather than tooling, and production lines need not be product specific.

The paper will illustrate the design and construction of a simple demonstration chassis, together with stiffness and performance data. Ideas for the application of the concept within vehicle manufacture and the automotive industry in particular will also be presented.

1. INTRODUCTION

Much of the rationale behind this project has been explored in the work of Lovins and others [1]. They suggested that the circumstances in which the automobile industry may well find itself within the near future calls for a rapid reassessment of vehicle manufacturing. Environmental pressures are demanding a radical step change in technology and procedures, rather than the traditional incremental refinements to existing design and manufacturing philosophy. This paper does not seek to provide an answer to that complex challenge, but merely to present an alternative manufacturing concept which could be adopted to meet at least some of the points raised by that research.

Sandwich panel constructions using metallic and polymeric honeycombs and foams have been used for many years in the competition and high performance sectors of the automotive industry, and there is considerable knowledge and confidence in their static, dynamic and crashworthiness properties [2]. However, it should be noted that with regard to vehicle structures, sandwich panels have only been used to produce extremely limited numbers of product and have been essentially hand-worked. This consumes large and expensive periods of time in order to maintain the required accuracy. Whilst handmade products have a certain appeal, the quality and repeatability of process and standards cannot be achieved by these methods within mass production.

In this paper we are exploring the potential of lightweight composites for chassis structures. However, we have taken a different approach to manufacture, in an attempt to circumvent the difficulties associated with wet resins, consolidation pressure and cure cycle control. This is achieved by machining, folding and bonding finished flat stock material, using standard CNC equipment. At first sight, this strategy sacrifices one of the principal advantages of polymer composites, namely the ability to mould complex geometries in one operation. On the other hand, the assembly of structures from flat sheet as described here has a number of advantages:

- No tooling is required.
- Existing technology CNC equipment may be used.
- Material quality is assured by the supplier, not the manufacturer.
- Direct integration between CAD drawing, FEA and CAM is straightforward.

These advantages have obvious implications for capital and production costs.

2. MATERIALS

The potential advantages of polymer composites for automotive parts (high specific strength and stiffness, corrosion resistance) are well known. Further benefits are available from the use of sandwich construction, in which a relatively stiff, strong skin is bonded either side of a much thicker, lightweight core. Sandwich panels have been widely used for structural applications in the marine, aerospace and performance automotive industries for several decades [3]. Lightweight core materials have included balsa, polymer foams and metallic, paper or polymer honeycombs. These have been used in various combinations with skins of carbon, glass and/or aramid fibre-reinforced polymer, as well as aluminium.

The principle of sandwich construction is that bending loads are carried by the skins, while the core transmits shear load. They enable large gains in structural efficiency, since the thickness (and hence flexural rigidity) of panels can be increased without significant weight penalty. Some representative properties of sandwich panels are given in Table 1.

	Thickness (mm)	Bending stiffness per unit width (Nm^2/m)	Weight per unit area of sandwich beam (kg/m^2)	Weight per unit area of monolithic Al. with same bending stiffness (kg/m^2)
F-board	13.7	1,100	3.08	15
	26.4	4,500	4.21	25
	52.3	20,500	7.54	41
M-board	13.9	3,500	4.67	23
	26.6	13,500	5.73	36
	52.0	52,500	7.84	56

Table 1. Comparison of beam stiffness of 'F-board' (GRP skinned aluminium honeycomb), 'M-board' (aluminium skinned aluminium honeycomb) and monolithic aluminium. Data courtesy Hexcel Composites.

While the design of sandwich panels for stiffness is relatively straightforward, design for strength is more complex. This is because sandwich structures exhibit a range of failure modes, depending on materials, geometry and loading. The most problematic are usually debonding of the skins and core shear failure. The energy absorbing characteristics of composites in general and sandwich structures in particular have been the subject of extensive investigation by a number of industries [2, 4, 5]. In all cases the use of such materials enhances the crashworthiness of the structure.

The prototype described in Section 4 used GRP skin/aluminium honeycomb F-Board, donated to the project by Hexcel Composites. This was used solely as a readily available material, and no attempt has yet been made to optimise the panel, either for performance or manufacture.

In high performance car construction, most sandwich panel elements are vacuum bag/autoclave moulded on a contact tool, usually in several stages (e.g. first skin; core to skin bond; second skin). Although this permits complex shapes to be produced on low cost tooling, it is necessarily a time consuming and labour intensive process. A high degree of cleanliness and sophisticated process control are required, and inspection is notoriously difficult. However, sandwich panels are also available as flat sheet, stock material. Hexcel Composites, for example, supply a range of honeycomb cored sheets of varying specifications which is widely used for building cladding, aircraft flooring, luggage bins and bulkheads. The use of a stock material is attractive, since primary material quality and specification becomes the responsibility of the supplier, not the manufacturer.

3. DESIGN AND MANUFACTURING PARAMETERS

The current and established philosophy of mass vehicle production uses cheap material, i.e. steel, and expensive press tooling. The method relies on a large output over a long period, utilising the tooling to its absolute maximum in order to achieve profits and recoup the initial enormous investment. Typically, a steel component’s costs are divided 15% for the steel itself and 85% for shaping and finishing [6]. There is much excellent research being carried out to improve the performance of steel and aluminium for vehicle production [7, 8], but all such research revolves around the use of existing tooling methods.

The majority of manufacturers and designers recognise the inherent advantages, and indeed the requirements, to reduce overall vehicle weight, whilst improving crashworthiness and strength.

Research into utilising composites in vehicle construction have been undertaken by most of the major manufacturers. What emerges is that all of these efforts are aimed at making new materials fit existing manufacturing methods. It has been said that composites are not "black steel" and that a component that looks the same in composite as it did in metal is incorrectly designed. Rather one must use appropriate materials with appropriate methods. This project does not seek to introduce new materials and try to make them fit into existing processes, but rather seeks to investigate the feasibility of redefining the manufacturing concept. This involves the opposite of the current ‘cheap material/expensive tooling’ philosophy; namely ‘expensive material/cheap tooling’.

Monocoque construction has proven itself the most cost-effective way of producing vehicles when using pressed steel methods. However, this method does not necessarily produce the strongest, stiffest or most efficient vehicles. Many highly regarded low volume vehicle manufacturers, such as Lotus and TVR use a chassis/body method which allows each area of the vehicle to use the most appropriate materials to perform specific tasks.

This project has begun by taking the concept of chassis/body construction one step further. The form of the chassis is expanded so that it forms a structural endoskeleton which provides stiffness, strength and the vast majority of passenger protection. If a stock, flat material had sufficient properties to be used without expensive, complex tooling and forming to construct such a structural endoskeleton, other areas of the vehicle could use materials more suited to their particular functions.

Several techniques are well established for the shaping and assembly of structural components from flat sandwich panel [9]. Some of these are illustrated in Fig. 1. Panels may be bent to required angles by removing a defined strip of material from the inner skin, then folding and adhesively bonding the joint. Similarly, panels can be joined at right angles.

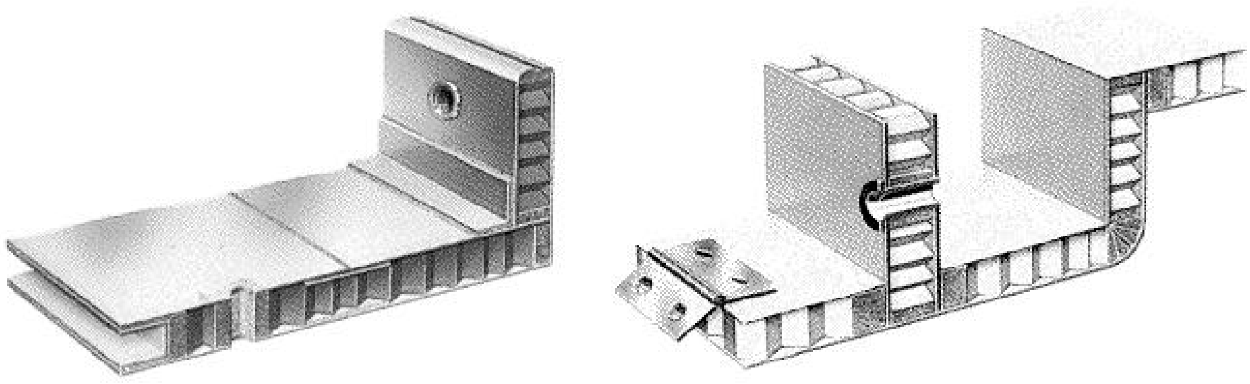

Figure 1. Some jointing methods for sandwich panels. (Courtesy Hexcel Composites)

For additional strength, reinforcing material can be added at the skin joints. It is emphasised at this point that the process of shaping a panel requires no tooling, and assembly can often be arranged so that parts are self-jigging. Although panels can be machined with hand tools, a major attraction of these techniques is the potential they offer for computer control and automation. In this project we have used a general industrial CNC router/cutter; as described in Section 4, adhesives were applied manually, but this too could be readily automated.

4. ‘UNICAR’ CHASSIS - PROOF OF CONCEPT

The student project undertaken in 1995/6 at the University of Plymouth aimed at a preliminary proof of concept. It was felt that the best way to achieve this was to design a vehicle endoskeleton (Fig. 2) on standard CAD software, and then to use the data directly with a CNC router to produce the required panels. These panels would then be bonded and some existing suspension and drivetrain components would be fitted to the resulting chassis.

The UniCar design was reasonably non-specific, other than it should be of average dimensions and capable of transporting six adults. Due mainly to suspension aspects, a Citroen 2CV was chosen as the component donor vehicle. The chassis was therefore designed to incorporate the leading and trailing arm suspension, but the drivetrain was reversed and mounted centrally, still driving the front wheels. This allows very simple mounting of the drivetrain and provides good dynamics as well as a more efficient use of the structure as it negated the requirement to cantilever the engine out of the front of the car. There was then also the added attraction of having the largest single mass underneath the vehicle occupants rather than in front of them, providing centre of gravity, safety and crashworthiness advantages.

Expected loads for the chassis were calculated at 22 kN and then doubled to provide a safety factor. Thus the maximum force transmitted to the chassis by the suspension would be around four and half times the mass of the vehicle, which equates to a force of about 40 kN experienced in a longitudinal direction when the vehicle traverses a bump. To transfer these loads to the honeycomb panels, a 110 mm diameter steel ferrule was manufactured through which the suspension arms would pivot. These were tested to 50 kN with stress propagation as predicted and without compromising the board or the ferrule. Mountings for the dampers were manufactured and successfully tested for similar loads.

The chassis was based on a beam design which provided simplicity with efficient use of the material and a structure which was continuous along the vehicle length, offering stiffness and a degree of front and rear impact resistance.

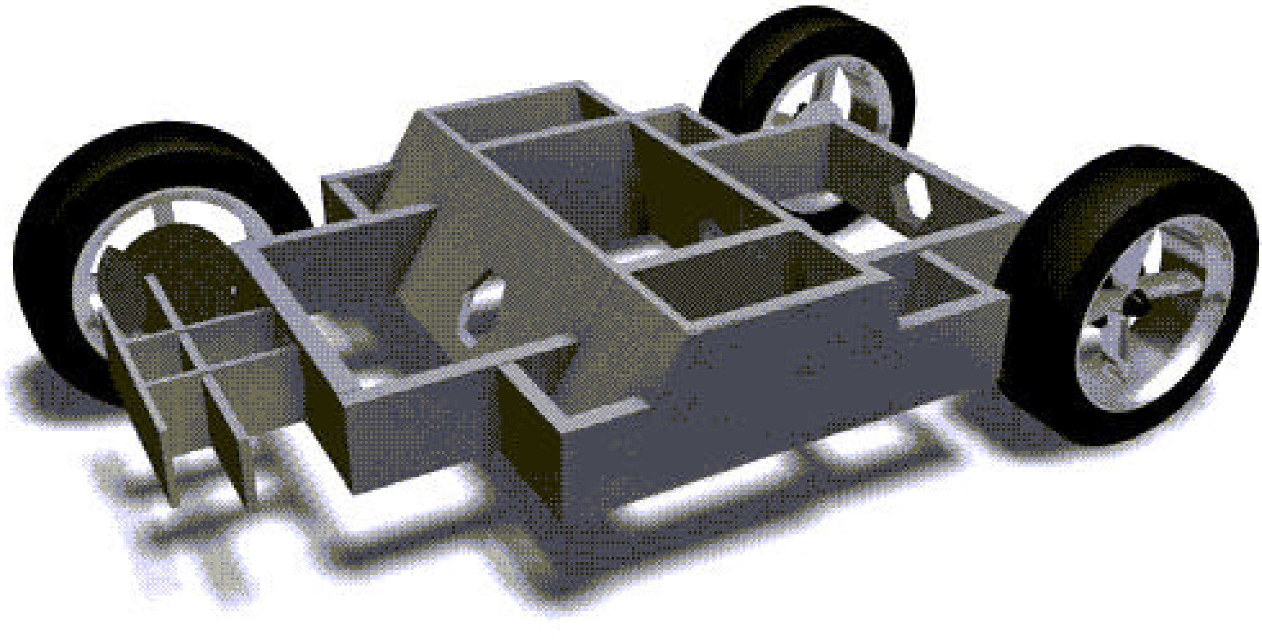

Figure 2. 3D computer model of the UniCar chassis concept

The chassis was designed to be assembled using the cut-and-fold methods outlined in Section 3, and after some 1/5th scale model-making using corrugated card, the sandwich panel components were drawn using AutoCAD. These drawings were then used by a local engineering company with a CNC router to machine the panels. The twin longitudinal beams were bonded first and then suspension components fitted to the panels. The panels were then bonded and the remaining components fitted. Bonding was achieved throughout the structure with Redux 420 adhesive applied with a special application gun.

Initial testing of the torsional rigidity of the chassis as a structure was performed. The chassis was restrained at three corners and then loaded at the fourth corner to induce torsion. Digital angle meters were used to measure angular displacements and dial gauges used to measure vertical and horizontal displacement. The angular displacement was validated using dial gauge displacement readings and their geometric relationships. For a weight of 48 kg, the UniCar chassis achieved a torsional rigidity of 5900 Nm/deg and a bending rigidity of 6095 Nm/mm.

Table 2 shows values for current state of the art (‘Reference’), Ultra Light Steel Auto Bodies (ULSAB), aluminium extrusion construction (Lotus Elise) and flat sandwich panel construction [8]. ‘Reference’ and ‘ULSAB’ are monocoque, whilst the other two are chassis/body constructions.

	Reference	ULSAB	Lotus Elise	UniCar
Mass (kg)	271	205	68	48
Specific torsional rigidity (Nm/deg)/kg	42.55	92.96	147.06	122.92
Cost (US$)	1116	962	n/a	560

Table 2. Relative torsional rigidities (data for ‘Reference’, ULSAB’ and Lotus from [8]).

These initial results are very encouraging, and suggest that the overall concept warrants further investigation.

5. MANUFACTURING CONCEPTS

The proposed manufacturing system is only possible now because of the advances in material quality, and computer systems, controls, software and machinery. Before the advent of cheap, high powered computing facilities, suitable accuracy, repeatability, quality and cost effectiveness were difficult to achieve.

In line with general industry process, the design begins on CAD software on the desktop. As the main structural endoskeleton is manufactured from flat panels, the drawing process and stress calculation are far simpler than with current monocoque construction. The panel data is fed to lofting software and then to a CNC router/cutter where the panels are cut directly. At prototype stage the chassis can then be assembled and bonded by hand. This is only possible if the panels are cut by the computer, directly from the drawings.

As the majority of crash protection is achieved solely by the endoskeleton, preliminary crash testing can be performed before manufacturing body panels. Overall dynamics and handling can also undergo preliminary assessment. Components can be test fitted; stylists can work on full size vehicles; fatigue testing, crashworthiness and so forth can then be tested. Modifications to panel weight, material specifications, a particular joint or component interface is simply made on the computer and generated at the manufacturing level. All of this essential preliminary development work can be undertaken without any model-specific tooling.

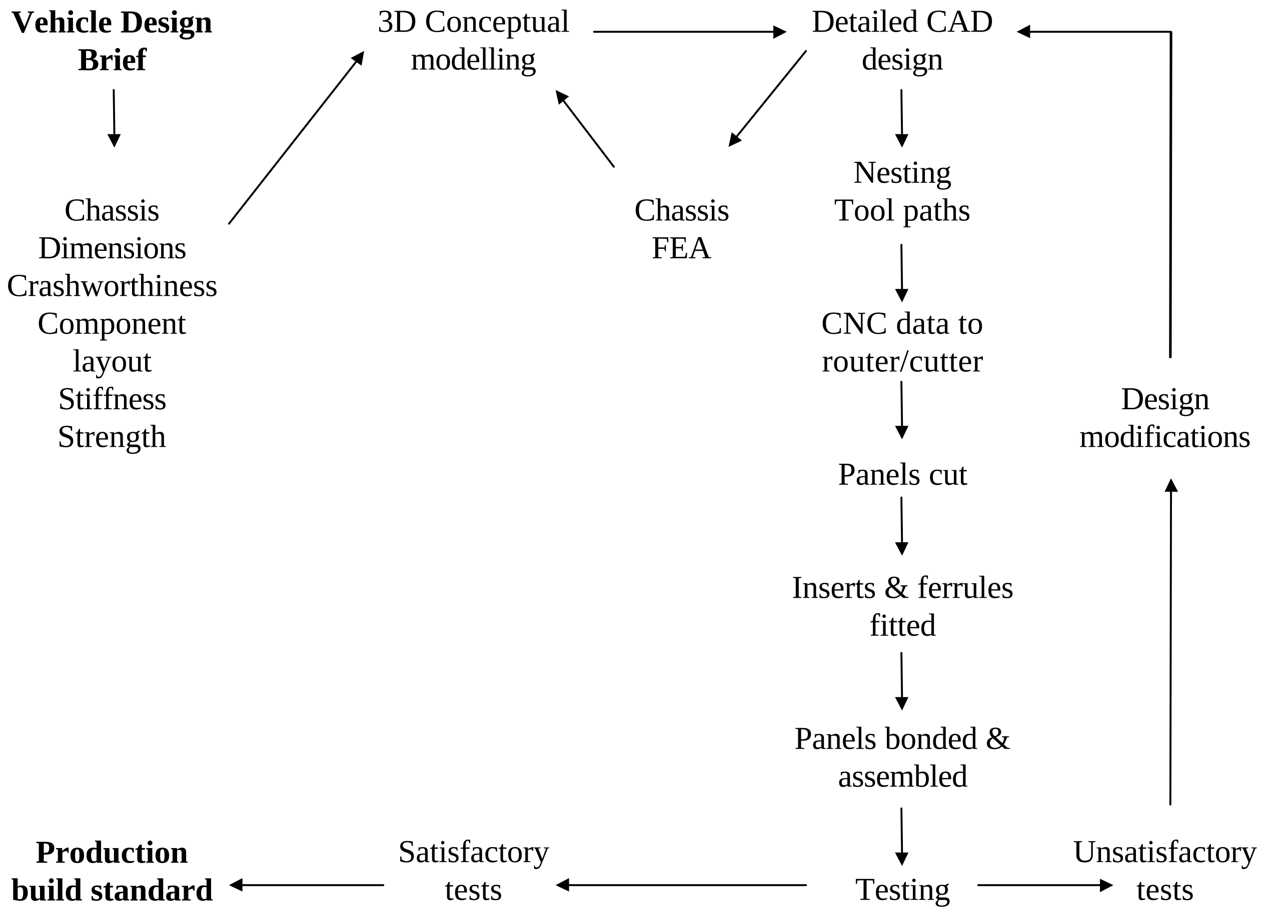

Figure 3. Simple flow diagram of chassis production process

In series production the whole manufacturing/assembly process is automated, but utilises simple folding and adhesive bonding robots, which are again, non-product specific.

In this case methods and materials for body panels are no longer constrained by being part of the monocoque. Simple panels made from a whole range of materials from plastic to aluminium and lightweight steels can now be utilised, depending on the vehicle's performance requirements, its function and intended market.

6. FURTHER DEVELOPMENTS

Having successfully proven that the manufacturing concept is feasible in basic engineering terms, work is currently in progress on chassis design and analysis. Although flat panel structures are relatively simple to model for FEA, it is necessary to quantify the mechanical properties of the bonded joints, and to represent these in the model efficiently. A longer-term goal is to further integrate the 3D CAD design with stress analysis, thus enabling materials and structural optimisation prior to manufacture.

In the current situation of limited resources, the following aspects are recognised as being of considerable importance, but must await further funding:

- Selection of sandwich panel component materials (skins and core) for ease and consistency of manufacture, performance and recycling.
- Optimisation of adhesive for cure cycle and long term properties.
- Crashworthiness testing.
- Robot handling and positioning of panels.
- Production plant layout, process monitoring and quality systems.
- Design and attachment of body panels.
- Operational considerations (e.g. thermal, acoustic and dynamic characteristics).

Funding and in-kind support is actively being sought from various bodies (e.g. materials suppliers, manufacturers and potential customers) to carry the project forward.

7. CONCLUSIONS

In this project, we have applied a long established material form (the principles of aluminium honeycomb were developed in 1938) and a simple assembly route to produce a complex, load bearing structure. The proof of concept chassis described here has given us confidence in the potential of this low investment manufacturing process. It is also providing valuable structural performance data which will aid future analysis and design.

A manufacturing concept has been outlined which readily integrates CAD/FEA and CAM. The benefits of lightweight yet high stiffness and strength composite construction are available with no requirement for component specific tooling, through a process which can genuinely be described as flexible manufacture.

We believe this work provides an exciting platform for future development, and we look forward to future collaboration with the automotive and composites industries.

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