SYNTHESIS REPORT

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HTLE : LOW WEIGHT VEHICLE - DESIGN OF ALUMINIUM ALLOY BODY STRUCTURES (LWV-DABS)

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3. Abstract

Current practice within the automobile industry is to design vehicles from sheet steel. A growing concern about the environment and the need to keep running costs to a minimum have meant thai automotive manu~acturers have been increasingly looking for ways to improve their products. There are a number of ways in which the energy usage of vehicles can be improved including aerodynamics and power train modifications. However this project looks at the designing of vehicles with a significantly reduced body weight. It is estimated that a reduction in total vehicle weight of 10% can lead to fuel savings of between about 3 and 10% dependent on the drive cycle used. A reduction in total vehicle weight of 109'o equates to a body weight reduction of 4-O%.

The medium term solution to weight reduction for vehicle bodies is to replace steel panels with aluminium. Alurninium body design can take two basic forms: monocoque construction and spaceframe construction. Monocoque construction implies simple substitution of aluminium for steel with somewhat thicker panels. Spacefiame construction is a more radical departure with the structure being a framework of ahu-ninium extrusions with ahminium or other materials for the sheet panels. The spacefkame approach has been attempted for very low volume production but this is the f~st attempt at mass market applications.

Automobile designers are very familiar with the designing of monocoque structures but are unfamiliar with the spacefiame concept and the design rules associated with it, .This project has established the basic design rules for the various options within.a spacefkame concept to enable the designer to make decisions on the methods to be used and also to provide some confidence in the success of designs. This includes both the structure itself and the integration.of other components into it.

The project has shown that a number of no~e design techniques can be used utilising sheet, extrusions and castings such that very good performance can be achieved both statically and dynamically. The project has also demonstrated the potential to produce these spacefiame vehicles with good acoustic performance. The repair of these structures has also been shown to be feasible for the repair trade.

There are however some questions still unanswered with respect to the ecobalance of alurrtinium vehicles which needs further study. Further work also needs to be carried out to put into practice the Iessons learnt on reaI vehicles.

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4. INTRODUCTION

This project provides the automotive designer with the tools to be able to design an alm-ninium spacefiame structure with a significantly lower weight than conventional steel vehicles. This involved looking at acoustics, ecobakmce, profile designs, node designs, integration and repair.

Acoustics
Noise transmission within a vehicle is an important aspect to consider because of the impact it has on reputation and customer appeal. Aluminium spacefiame structures wilI have a significant effect on the acoustic performance of vehicles and it is vital that optimum low noise levels can be achieved. By using previous experience from steel vehicles and dynamic laboratory experiments this task established the design considerations for achieving the desired optimum performance.

Ecobakmce
The ecobalance work assessed the environmental impact of aluminium spacefiame vehicles to establish the improvements achievable in terms of COZ emissions. This information enables designers to take COZ emissions into consideration from an early stage. The task looked at the energy consumption at all stages-of the extraction of the aluminium, fabrication and manufacturing into a vehicle, the fuel consumption of the vehicle and subsequent disposal. The output, in the form of computer software, can be used by the partners as a design tool to compare the total energy associated with the use of aluminium to other material usage.

R-ojile Design
The profiles used to make aluminium spacefi-ame structures need to be designed such that they can perform structurally in both static and dynamic loading. This approach looked at the potentia~'m terms of extrusion design using computer design techniques (both FE and non-FE types) for achieving structural performance and then these designs were verified using simulators and structural testing (not fully completed). In addition there was also investigations of larger scale subassemblies to establish the interactions of the profiles and the nodes designed in 4.2.1. This culminated in the build of large scale sub-structures for further testing and validation to optimise in terms of weight, stiffness, fatigue and crash performance.

Direct Welded ATode, *Sheet Node, Cast Node Design*
The profiles used to make aluminium spaceframe structures need to be joined together at the nodes which are fundamental to the structural performance of the structure. Three types of node were studied independently to generate the best possible designs for each type. The work established designs using computer analysis techniques and **then those** designs were verified under static and dynamic loading by building up joint simulators. The tests on the simulators include static bending, torsion, fatigue and impact studies. The guide-lines will ~ delivered in the form of charts and graphs to enable the partners to scale up or down according to a chosen application.

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Integration ofcornponents

A design study was undertaken utilising the previous experience of the partner and sub-contractor to establish how the engine, mechanical components and trim items can be attached to a spaceframe structure using the profile and node design rules established in 4.2.1 and 4.2.2. The work developed optimised rules for achieving structural performance in the attachment of all other components. This then forms part of a design strategy which will include considerations for tolerances and joining techniques in an assembly environment. The rules will be delivered in written form.

Re air of Major and Minor damage

A 7repair route for spacefkame structures following major impact damage needs to be developed such that profiles and nodes can be removed and replaced. Initial work concentrated on establishing the level at which repair will be acceptable and demonstrating this on a laboratory scale. A strategy was then produced for disassembly and reassembly of the profiles and nodes. This task also included the aspect of design for recyclability which is closely related to ease of disassembly, speed and cost of repair which will be an integral part of the repair manual to be produced (being printed).

Design of Hydroformed Front End

Hydroforming is potentially an attractive way to produce structural members where it is advantageous to vary the section profile. Basic ,extruded profiles maintain the same section throughout their length but hydroforming can be used to give significant changes of form. This is particularly relevant to the engine bay area where a change of form is necessary to fit around the engine and suspension components. the other advantage of hydroforming is that compared to conventional sheet members there is a significant reduction in p[arts. Using sheet technology a front end would have perhaps three times the number of parts compared to hydroformed parts. This clearly cuts the manufac~ring cost. This task set out to establish the feasibility of using aluminium h~droforms for the front end in terms of manufacturability and also structural performance. This task is outside the original remit of the project and is not funded. it is also not yet completed.

5. TECHNICAL DESCRIPTION

Acoustics

Special test equipment was developed to determine the characteristics of panels and structures fixed in a stiff frame. FE analysis was performed and showed good correlation to the experimental results. Using bitumen heavy layers a similar acoustic behaviour to damped steel can be obtained.

The results show that the material substitution from steel to aluminiurn panels in spacefiame concepts is not acoustically criticaI. A weight reduction of about 30% in the panels will be realised in a real car although stiffness reduction with aluminium must be compensated for. An overall weight reduction of 40% seems obtainable.

Ecobalance

A lifetime ecobalance for the aluminium car body has been established. The environmental burden of energy use and C02 emission was evaluated step by step for the aluminium car body and a screening comparison with a steel concept was made.

The results indicate the difilculty experienced in trying to compare structures made of different materials. No clear benefit for alurninium has been demonstrated in this work and it is clear that fimther work is needed.

Proji[e Design

The work highlighted the viscoplastic behaviour of the alurninium for various strain rates. To quantifj the energy absorption, the “specific energy” for each type of profile was calculated to enable a comparison of the performance of steel and aluminium.

The second aim was to deveIop the front block of an ahuni.nium alIoy spacefkame structure. Firstly the behaviour of a primitive structure with only integrated profdes was evaluated. Work concentrated on the frontal impact (0°) performance at 55 lcnih with a Iirnit to the deceleration level of the car (under 40g to start).. Optimisation led to the final geometry which gave an acceptable performance. Finally the good behaviour of the structure was verified by testing both statically and dynamically.

Direct Welded Nodes

The starting point was a reference structure and a seIection of nodes to be designed and investigated in the further tasks. The calculation of crash behaviour was carried out using existing non-FE software extended to compute single-, double- and muIti-cellukir extrusions. Static and dynamic tests were done to verify the analytical equations and assumptions as well as the proper ru,pning of the software and there was good correspondence between software results and tests.

A design based on alurninium profiles with direct welded nodes is one of the fundamental design methods for alurninium”. The work done at direct welded joints confms the technical feasibility of such a vehicle structure but gives also indications that there will always be a sheet metal content.

After sample manufacture, an extensive test program showed good performance under crash conditions. Static performance aIso exceeded the targets.

Sheet Node Design

A reference space-frame structure was modeled using extruded tubes. Structural targets were assigned to the structure and an FE model deveIoped. The result obtained, via numerical simulation, was satisfactory. Numerical simulations were also made to determine the impact performance for hollow rectangular members.

Different geometric model nodes were studied by assembling together stamped sheets with extruded beams using either adhesive bonding or arc welding. The reference technique to join the shells to each other was adhesive.

Investigations of the structural behaviour have shown that the stiffness value is equivalent to a steel node and good performance can be obtained with a weight saving of 15 to 30 %, although poor behaviour was exhibited under crash conditions.

Cast Node Design, Integration and Repair

The aim was to develop cast connecting joints (nodes) for aluminium bodies. A spacefiame structure was investigated using nodes and profiles to validate the use of aluminium. The spaceframe would be constructed such that aluminium body panels could be added to complete an aH aluminium car body.

The project concentrated on one discrete node; the middle A post node. This joint is generally the most stmcturally critical and technically difficult to design on the majority of cars due to four major structural members converging in this area.

The integration task looked at joining parts to a spaceframe where build techniques need to be modified. The repair task looked at minor and major repair. It concentrated specifically on what needs to be done differently for aluminium spacefiame vehicles compared to monocoque steeI vehicles for the repair trade.

Design of a Hydroformed Front End

For reference a steel car, the Opel Corsa II, was chosen. The design of the complete hydroformed front structure had to meet the same package conditions as the base vehicle. The front structure was developed with hydroformed closed profiles because this technology has good potential for crash behaviour, stiffness and weight reduction in comparison to conventional tooliig design.

Based on this design proposal a stiffness calculation was done for the steel version and the alurninium hydroforrned version. The alurninium version showed a loss of **790 in** comparison to the steel version with a weight reduction of about 7%.

For hydrofonning the ASE-process, was selected. One node from the complete front structure was designed, optimised and manufactured. It demonstrated that the process is feasible for this type of application. The quality of the part however needs to be improved before it could be used orI a production vehicIe.

6. RESULTS

Acoustics

- Using bitumen heavy Iayers similar acoustic behaviour to damped steel is obtained.
- An overall weight reduction of 4@ZG seems obtainable with good acoustic behaviour.

Ecobalance

- *The* results indicate the diffkulty in trying to compare structures of different material.
- No clear benefit for aluminium has been demonstrated; t%rther work is needed.

Profile Design

- *The* optimised front block showed good results in crash testing.

Direct Welded Nodes

- Static and dynamic tests agreed well with the software results.
- The work done at direct welded joints confms the technical feasibility of the vehicIe structure but gives also indications that there will always be a sheet metal content.
- The test results obtained showed a good performance under crash conditions.
- Static performance exceeded the targets.

Sheet Node Design

- A space-frame structure was modelled using extruded tubes and the numerical sirmdation gave satisfactory results.
- Numerical simulations were also made to determine the impact performance and the resuIts exceeded the targets.
- Investigations of the structural behaviour of adhesive bonded sheet nodes have shown that the stiffness value is equivalent to a steel node and good performance can be obtained with a weight saving of between 15 to 30 $%, although poor behaviour was exhibited under crash conditions.

Cast Node Design, [nkgration and Repair

- The cast node work showed that a practical design in terms of predicted performance could be designed and manufactured.
- A practical design for a casting could feature parts integration to reduce overall costs.
- The integration task showed how to join parts to a spacefrarne.
- The repair task showed overall feasibility for spacefiame vehicle repair although at higher-cost than for steel vehicles.

Design of a Hydroformed Front End

- The aluminium hydroformed front end parts showed a loss of 7% in comparison to the steel version with a weight reduction of about **7$10.**
- **The** process has been demonstrated to be feasible for this type of application. The quality of the part however needs to be improved before it could be used on a production vehicle.

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7 . CONCLUSIONS

Acoustics

The results show clearly that the material substitution from steel to aluminium panek in spaceframe concepts is not acoustically critical. A weight reduction of about 3070 in the panels will be realised in a real car with equivalent performance to that of a conventional current steel vehicle. To meet the acoustic targets in a spaceframe car there are further requirements concerning the stiffness properties of the spacefkirne. Simulation studies have shown that the stiffness reduction by the akminium must be compensated for. Therefore an overall weight reduction of about 409Z0 seeps obtainable.

Ecobdance

Ah.mwkium irwento~

1) The fwst thing we can conclude was that the use phase was the largest energy consumer and source of COZ emissions. It was about ten times larger compared to the production phase calculated on the lifetime of the car.
2) The choice of allocation method for the recycled material was important. The method used gives high credit to the recycled material, which makes recycling very profitable and necessary to get good energy economy and lower COZ emissions.
3) For the production phase it can be concluded that the extraction of bauxite and production of primary alurninium takes about one tenth of the energy required to produce aluminium.

Comparisofl akninium - steel: ZX-Z13:

For many reasons, it was impossible to realise the comparison between the ecobalances of the **ZX** and theZ13. But some parameters have been pointed out because of their huge influence on the results. For further studies attention must be paid to these. parameters and the assumptions must be fully transparent.

Screening comparison dwninium-steel:

The concision of this comparison evaluated with the EPS system is that the difference between aluminium and steel over the total life cycle is very smalI, although the aluminium concept seems to be environmentally better. However, the probability that aluminium is better than steel is only about 60%. So the choice between the two concepts is very difllcult and the choice of assumptions is critical. The production of ah.nninium is more energy consuming and CO_z emitting than steel production. But, regarding the recycling scenarios and the allocation method, the difference is lowered. The final results over the life cycle are mostly dominated by the use phase. This dominance makes the following parameters very crucial:

- the **390 fhel** consumption reduction for a 107o reduction mass,
- the choice of O,61I1O km,
- the driving distance.

A change on one of these assumptions can radically rnodi~ the final results of the study.

In conclusion the difference between the two vehicles was very small, ad for further studies attention must be paid to the choice and the transparency of the assumptions at the beginning of the study.

Proj21e Design

Good crash performance can be obtained using profiles in aluminium for the front end of a vehicle. Simulation of the performance gives good agreement and rules have been established to understand where the simulation differs from the real case. The calculation tends to overestimate the stiffness of the front end leading to a higher level of deceleration than the experimental values. This c'm be explained by:-

- the constitutive law, even fitted with adapted parameters, does not represent the exact behaviour of aluminium. It is important to develop a specific constitutive law taking into account the anisotropy and viscosity (even if low) of aluminium.
- the assembly modeling does not enable good characterisation of spotweld rupture or the heat affected zone which was greatly w{akened. It was impossible to mesh the weld bead: a large model would considerably increase the calculation time.
- the geometry does not exactly correspond to reality as it was difficult to model accurately the junctions between profdes and panels. This last remark was due to the fact that it was undesirable to penalise the calculation efficiency introducing too small elements (minimum dimension for a quad is 15 mm).

Direct Welded Node Design

A task by task evaluation leads to the following statements:

- The closer to real vehicle package conditions the higher the general acceptance of achieved results.
- The calculated figures and diagrams coming from the new impact performance software module are much more precise than expected.
- Compared to the purpose to have a tool to make comparisons and decisions in the conceptual stage of structure design, a very good tool has been developed.
- Direct welded joint design is consistent to a very high degree with any given vehicIe package.
- There has been found a "simple" solution for a generally critical area of the vehlck's side members. Bent extrusions and,rnuch more complicated (and expensive) end cuts won't be better from the beginning.
- Static crush-tests finally confined the principle design of the main energy-absorbing elements of the front structure: a step-by-step increase of energy absorption capability has been proved.
- The dynamic crash of the front structure confined the advantages using aluminium for energy absorbing reasons. Furthermore, the design of the main force transmitting members has been proven once more.
- The correlation between caIcplation and test results was better than expected.
- Detecting fatigue-behaviour of separated sub-assemblies under real conditions was difficult. A better approach wouId be a special test-arrangement only to compare the possible variants.

Sheet Node Design

Building an aluminium space frame, the stamped sheet node design represents an opportunity to realise the connection among the ex@ded beams. They offer the advantage to not realise very rigid constraints (they can deform locally without compromising performance) during the assembly process of the frame and also they don't require specific processing of the beams.

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Designing such a node, rnechanicaI performance (like stiffness) has to be considered f~st; strength (stresses under yield point) was generally automatically assured. The sheet thickness is d,riven by node stiffness targets. Generally the high value of the thickness employed, if compared to steel, reduces the risk of local buckling. From the point of view of the perforrnanc~, sheet nodes exhibit stiffness values comparable to conventional design with a weight saving ranging from 15 to 30% while the behaviour under impact load seems to be poor.

Adhesive bonding has been recognised to be the best joining technique either to link the shells to each other or to cmme~t shells with beams. OnIy open section assembly sequence has been considered to minimise the risk of removing the glue during the manufacturing process. A good value of overlap has been shown to be 60 to 70 mm. Also butt welding, between node and beams, has been considered; this technique offers good performance but it presents diffkulties during the node realisation.

Cast Node Design, Integration and Repair

It can be concluded from the cast node design work, although the testing is stiLl to be completed, that cast nodes can be designed where they are usefid, despite the high cost of the parts. Complicated designs which integrate a number of features such as the hinge reinforcements can be manufactured to fairly good tolerances with predicted good performance. The testing will prove the real life performance of the designs, however the material properties established in the MABS project are good.

The integration of all other vehicle features into a spaceframe vehicle is relatively straightforward with no major concerns regardless of the node technique employed.

A set of procedures for minor damage repair has been established which can give adequate p&formance. These procedures are relevant to the repair trade as it exists today. A set of procedures ha? also been proposed for major damage repair but these have not yet been fmal]y verified.

Design of Hydroformed Front End

The results for the hydroformed front end show that this technology can general~y be used for production of s&uctural body parts in aluminium. Main limitations however are given in the low material elongation of aluminium which allows only small changes in profile sizes and in limited available joining techniques. For these two aspects further studies for improvements are required.

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Finally I would like to acknowledge the tremendous atmosphere that was setup during this project and its sister LWV projects. The level of teamwork, information interchange and social interaction was of great value to all of the participants as well as to Europe as a whole. There is now a great understanding of the issues associated with Low Weight Alurninium Vehicles and a network of contacts across the whole of Europe. It is certainly hoped that this network will continue after the end of the project.