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NIANUFACTURING ASPECTS OF’ ALUMINIUNI BODY STRUCTURES (MABS)

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3. ABSTRACT

Today, most of the cars are manufactured the same way, using techniques based on steel sheets, the deep drawing or stamping of these sheets and their assembly by resistance spot welding. For weight saving, the use of aluminium is one of the most promising ways. New problems need to be solved because this evolution reveals an important gap refering to the actual processes and habits:

- aluminium can be used as thin sheets, but also as profiles and casting parts

- casting processes need to be adapted to automotive requirements: technical and economic competitivities, soundness of cast parts and convenient service properties;

- forming processes of profiles are badly known from car makers and for their production rates. Even for sheets forming by deep drawing, the problems are specific and the process parameters (bkmkholder force, lubricant...) are to be considered and re-defined for this purpose.

- assembling. Spot welding remains possible for aluminium joining but needs to be improved (resistance of spot welded zones, lifetime of electrodes...]. If other types of parts are concerned, such as castings and profiIes, new joining techniques have to be used: seam welding, bonding, mechanical fastening and mixture of these processes.

In the MABS Project, the aim of these manufacturing aspects are:

- to check briefly the actual knowledge and applications in all the problems described above,

- to study the feasibiIky and limits of all these processes,

- to realise, firstly laboratory parts, then the tools leading to prototype parts. These parts will result of the best compromise between designs, materials and processes,

- to assemble these prototype parts with new joining processes and realize representative nodes,

- to characterize the behaviour of these simple nodes, relatively to mechanical, corrosion and durability aspects.

Guidelines have been established, classified and published: they have covered most of the situations which will occur in a real mass production.

The potentiality of all the forming assembling processes has been evaluated and compared mainly on technicaI level.

The economical approach is more difficult. Gained data have to be reconsidered taking into account the in-house policy of each car manufacturer.

This Project is part of the Low Weight Vehicle Programme and is therefore complementary to the other three Projects: “Surface Treatment and Corrosion of Aluminium Alloy Body Structures” (SCABS), “Design of Aluminium Alloy Body Structures” (DABS) and Properties of Aluminium AHoys for Body Structures (PABS)

4. INTRODUCTION

A complete validation of the industrial feasibility of car structures in mass production is in fact, only operative after numerous and expansive trials. Nevertheless, in this MAJ3S Project, significant results have been gained concerning industrial and manufacturing aspects. These data even not complete allow:
- to reject initially foreseen solutions,
- to choose between different process parameters,
- to quantify the progresses gained during this project,
- to evaluate the capabilities of different processes to obtain a given functionality,
- to define the areas which remain unexplored, in order to solve existing problems.

1. Sheet technologies
For difficult parts, one stamping stroke more is necessary. Tool shape has to be modify comparatively to steel; recommendations have been established. Specific lubricants have been chosen within the compromise lubrication-decreasing. EDT seems the most efficient surface roughness in view of friction and galIing. No strain effect has to be considered for deep drawing. Tailored blanks are more useful~ than for steel to compensate the higher material cost (the right material and thickness at the right place): filler material is to be used. Spring back is critical for amuminium; numerical simulation is a useful] way to control it but further works are already necessary to success with this approach.

2. **Profile technologies**
Stretch bending without mandrel is the most promissi~g way. For simple shapes, for example 2 D ones, press bending can be sufficient. Formed profiles seem difficult to use for cosmetic external parts. The final geometrical accuracy E 0.5-1 mm is sufficient in view of assembling by seam welding'. Tools have to be non nominal ones due to spring back.

3. Cast technologies
Three processes were finally selected: vacuum pressure die casting, indirect squeeze casting and thixocasting.
Length/thickness 500 mm/2-3 mm can be achieved. Conditions have been established to produce heat treatable and weIdable cast nodes. Yield stress are within 100-280 MPa. The proposed parts were very selective ones. Even if some results could not be obtained, the studied processes after some modifications can be used for more simple parts. Economical analyses lead to rather high costs but they have to be compared with other processes used to manufacture nodal areas.

4. **Joining technologies**
For resistance spot welding, a medium frequency technique has been developed to weld correctly without sheet surface preparation. Tip life duration is around 200 points but this result is controversial depending on the last developments realized is the PABS Project and outside the LWV Projects by Al supp~iers and car manufacturers. MIG is better than TIG for profile-profile assembling; maximum gaps up to 1.5 mm a~e acceptable.
C02 laser welding has to be chosen rather than the YAG one for sheet assembling. Bonding alone has to be avoided; mechanical fastening avoids deleterious behaviour in peeling situation but is not useful for shearing loading.

All data gained in this MABS Project define more precisely the forming, joining and usability limits of AI semi-products. These information will heIp to draw aluminium cars. These results are akeady used by each partner for internal confidential and competitive purposes. Out of the purely technical field, partners have learned to work together. Car manufacturers and AI suppliers and each of them know more precisely the relative requirements and possibilities.

5. TECHNICAL DESCRIPTION

Sheet technologies

- Renault

Prototyping of large parts

This whole Project “Low Weight VehicuIe” is devoted to a space frame approach of the body in white. Nevertheless, some structural parts cannot be achieved only with profiles. The aim of that study is to appreciate the formability of great dimension structural parts.

Two parts are studied:

- TWINGO turret: the stamping is leaded in two operations because of difficulties to form the centraI zone.
- SAFRANE hinge reinforcement: two tools are compared, one made in concrete resin and the other in iron cast.

Two alloys -5182 and 5754- are tested to appreciate the formability.

- FIAT

Prototyping of small parts

The technical activity performed by FIAT in this task was finalised to the assessment of aluminium alloys drawability and to verify the technological feasibility of structural stamped nodes.

Laboratory tests were carried out on four different aIloys grades and different lubricants to evaluate the limits of formability of a~uminium and the effects of lubricant on friction coefficient.

Two different dies were made for the stamping of the structural nodes.

- H A

Tailored blanks

The aim is to develop and to evaluate the Tailored Blanks technology for Aluminium sheets. This process is important in order to optimise scrape rate of sheet and to decrease the number of assembly operations of stamped parts. The work performed is to define the most suitable joining process and to evaluate the formability of the taiIored blanks.

- Adam Opel

General comments

The application of aIuminium in the automotive industry requires different technologies in comparison to steel. In this Project, the most important technologies have been worked out and fundamental applications were tested.

Extrusion profile technology can be used with alurninium in contrary to steel. Almost every shape of closed or open profiies can be produced and various additional functions can be integrated.

Joining techniques like bonding, cIinching and riveting and also combinations of thes; joining techniques have been investigmed in this Project. Welding techniques like MIG, TIG, laser and electron beam welding were tested in comparison to spot welding. Also sheet metal drawing technologies and different kinds of castings were used for samples and prototype parts.

Profile technologies

- PSA

Dimensional forming of profiles

Designing and manufacturing of space frame structures need the development of a specific knowledge about forming of Ahminium profiles.

Industrial potential processes are investigated and forming limits of representative profiles used in a space frame are defined in order to provide guide lines to designers.

- Renault

Industrial approach of profile forming

Forming of profiles is considered using stretch bending. Tests are performed on 2D and general 3D parts. For stretching control has to be realised by strain or displacement rather than by stress or load. Partly soft tools are used to allow progressive approach of the final shape. Forming limit rules are established integrating alloy profile section and final shape of the part.

Industrial efficiency integrating technico-economical considerations can only be partially described because it has to circulate the whole functionality of the part.

Casting technologies

- Renault

Indirect Squeeze Casting and Vacuum Pressure Die Casting

ISC and VPDC are compared. Limits of the methods are searched including shape difficulties, wall thickness and specific unusual alloys. Around 200 nodes were produced.

The technical study is fulfilled but the economical evaluation is more difficult ; further tests on a higher number of parts is necessary to confirm the estimates in tool life duration,

- PSA

Thixocasting

The Thixocasting process potentially allows manufacturing of accurate, weldable, heat treatable parts with high mechanical properties and a short cycle time.

The aim of this task is, first to evaluate the material properties achievable with industrial equipment and second to study the feasibility of nodes which are closed and Iarge parts with thin walls.

- Volvo

Vacuum Pressure Die Casting

The work carried out has mainly consisted of
evaluation of new casting processes Vacuum Pressure Die Casting, Thixocasting and Indirect Squeeze Casting regarding geometrical and mechanical limitations by casting a complex shaped spaceframe node.

Joining technologies

- BMW

Spot welding

Due to limited energy resources and environmental protection , weight reduction of car bodies will gain increasingly in importance. To use aluminium in car bodies will gain increasingly in importance. To use alurninium in car bodies is a very promising way for we$ht reduction. However, sheet aluminium can be presently spot welded with satisfactory quality only by means of pedestal welding machines. The joint tongs currently used for sheet steel are unsuitable for aluminium owing to its particular physical characteristics. Suitable joint tongs are required for automated large-scale manufacture in the automotive industry. The objective of this part project is to develop suitable joint tongs for aluminium.

- RenanIt

Welding MIG TIG

The main study concerns joining profiles on cast parts. TIG was cancelled for poor properties of the joints and a poor ability for industrial robotization. MIG welding parameters are defined. The sensitivity to the cast soundness is very high. Additional studies on profile /profile joining with sensitivity to geometrical gaps before joining is studied carefully.

- FIAT

Adhesive bonding and mechanical fastening

The technical activity performed by FIAT in this task was finalised to the analysis and optimisation of joining processes. Three different technologies were studied:

- laser welding;
- adhesive bonding;
- adhesive bonding plus mechanical fastening.

An analysis of assembly processes was performed to evaluate the tolerances of stamped parts and the influence on the precision of a simple frame.

- PSA

Mechanical fastening

The resistance spot welding technology currently used for most of the joints of steel structures meet some specific problems when applied to Aluminium parts.
Mechanical fastening (clinching and riveting) is an alternative technology. The aim of this task is to define the industrial parameters of realisation and to evaluate their mechanictd behaviour in comparison with resistance spot welding and bonding.

- Daimler-Benz

Electron beam welding

The objectives of the task “Electron beam welding” were the determination and definition of suitabIe electron beam welding parameters for a selected aluminium alloy combination, a metallographical and mechanical characterization and finally the realization of an electron beam welded structural demonstration part.

6. RESULTS

Sheet technologies

- FLAT

Laboratory deep draw tests

The main results are the following ones:

The drawability of aluminium sheet is poor compared with that of steel sheet.

The lubricants play a very important role in deep drawing of aluminium sheet.

The Alusuisse 6016 T4 1.2mm aluminium sheet is proved to be the best among the tested aIuminium aIIoy sheets for deep drawing.

- The EDT surface finishing resulted better than the mill or the laser ones.

Draw-bead tests (on 6016 T4 EDT 1.2mm andP040.8mm) have given results on friction coefficient evaluation: the behaviour of aluminium and steel is similar. For low clamping pressure, aluminium and steel have almost the same friction coefficient, with increasing load the aluminium friction behaviour becomes better then steel, but there is a point beyond that it begins galling phenomenon that modifies finishing and plasticity status of surfaces.

The recycled shredder aIIoy (from 6016 alloy) has a performance not far from that of 6016 alloy, with only a little difference in strain level.

The general guidelines for stamping ahminium alloys were defined

- The FEM simulation of stamping process reduces the set-up time

A stamping cycle for the structural node was defined

- Renault

Protyping of small parts

- the tool radius must be increased to permit a large metal flow. With this modification it is possible to stamp in good conditions.

the thickness measurements show a strong influence of the aIloy mechanical properties.

- PSA

Tailored blanks

Welding with C02 Laser and filler wire of shear cut blanks has been defined as the optimum according to quality and industrial constraints.

Naka.zima test has been the most significant procedure to evaluate the drawability of the blanks according to its constitution (material, simple or multigauge blanks) and to the position of the seam weld versus distortion direction. The formability is very sensitive to the presence of defects in the weld.

Validation has been carried out on a representative part.

- Opel

General Comments

The whole Project was organized to find out fundamental knowledge based on typical sampIes of production parts or applications in automotive industry. The good cooperation between the Projects DABS, PA13S & SCABS with MABS finally lead to a good understanding of advantages and disadvantages of the technologies being used. In detail, the results allow to select a joining technology based on each special requirement like f.i. fatigue, stiffness, production time or cost. Advantages of the space frame concept, using extrusions in comparison to the conventional tooling concept were worked out. Also sensible areas in sheet applications, like spring back behaviour have been taken into account. The application of different casting technologies have shown pros and cons for castability and tooling costs.

Profile technologies

- PSA

Dimensional forming of profiles

Stretch bending appears as the best process to manufacture bent profile parts with good shape fitability and surface aspect.
Thinning and breaking of walls don't appear as critical phenomena, as section collapse occurs first. So, total elongation of materials is not a first order characteristic for profile bending.
Cumulative effect of bending radius and bending angle shows that rather small radii can be reached if bending angle remains small.

- Renault

Industrial approach of profile forming

Stretch bending is the most promising process for 3D bending. Stretching has to be strain - rather than stress controlled. Use of non rigid tools allow a very rapid setting up of correct final tool shape to integrate the spring back effects.
Internal mandrell has to be avoided for real mass production. Geometrical accuracy is around 0.5-1 mm i.e. compatible with the assembling processes by **seam** welding.

Casting technologies

- Renault

Indirect Squeeze Casting

Feasibility of cast nodes has been demonstrated considering the combinations: process (ISC-SSM-VPDC) versus alloys. Geometrical accuracy is not satisfactory with ISC; further modifications are necessary. Mechanical properties yield stress - strenght are high enough. Elongations are sometimes low but is it crucial? Manufactured nodes are heat treatable and weldable. Economical analysis reveals rather high cost compared to steel solutions.

- PSA

Thixocasting

The properties in terms of yield and ultimate strength are very high. Nevertheless, the elongation is rather scattered.
The fatigue limit of machined specimens is satisfying. But, the fatigue limit of treated and unmachined specimens is significantly reduced due the presence of few small blisters in the skin. The work carried out on representative and real parts shows that it is possible to cast thin walls only with a limited path flow. For long path flow, thickness has to be increased or casting to be assisted by vacuum.

- Volvo

Vacuum Pressure Die Casting

Vacuum Pressure Die Casting and Thixocasting SSM with Vacuum assistance.
A spaceframe node with a closed box thin wal~ed geometry has been realized in high vacuum pressure die casting and SSM with an inner sliding, split steel core. Vacuum is necessary for mould filling.

Indirect Squeeze Casting. The same but longer spaceframe node version has been possible to manufacture in Indirect Squeeze Casting with a pressure resistance sand core.

Joining technologies

- BMW

Spot welding

The main results achieved are:
A useful new medium frequency joint tong has been developed.
The mechanical properties of the spot-welded joints have been investigated.
The most suitable surface treatment for spot-welding of aluminium has been developed (Ti-Zr coating).
The optimal process parameters have been determined.

- Renault

Welding MIG TIG

Evolution of MIG-TIG welding led to the final choice of MIG welding, less sensitive to gaps between the different points before assembling. Most of the trials concern cast node - profile assembling. Female node configurations is the most convenient. Welding properties are very sensitive to the casting quality. VPDC led to the highest properties of the joints.
AH welding parameters have been optimized and beta coefficient is around 0.6-0.7.
Maximum allowable gap is G 1 mm.

= FIAT

The main results are the following:

CO_z <u>Laser weldin~ of lau joints</u>
~iections of the laser beam into the optical path were avoided tilting the focusing head of about 15°. The best shielding conditions were obtained using an external 10 mm nozzle (slope 300). Underbead shielding was effective in reducing "drop-through" for thicker sections. For some joint configurations, the use of filler wire led to an improvement of the weld quality in terms of geometry and defects. The tensile strength of the optimised joints varied from the 53% of the base material for the 6111 alloy up to the 93% for the 5182/60 16 joint.
The preliminary trials on "T-node 1" (6016 alloys; 1.2 + 1.2 mm stamped sheets; 2D weld path) showed good feasibility. Two different optimised shielding conditions were achieved with either external nozzles or laser beam coaxial nozzle. The best results were obtained using the external nozzles, but a coaxial flow was necessary to achieve good shielding conditions along the T-node 2D welding path, using a 5-axes robot. The welded material showed low porosity and no cracks.

<u>Nd:YAG Laser Weldin~ of la~ ioints</u>.
To provide the threshold power density, the pulsed operating mode was necessary. Good results were achieved using the **6016** alloy in terms of both low porosity and cracks and weld bead geometry.

<u>Adhesive bonding</u>.
The mechanical behaviour of the bonded joints is affected by the adhesives type and gap. When the adhesive gap grows from 0.2 mm to 2 mm, there is an immediate 50 % reduction in terms of shear resistance and the fracture is transformed from cohesive to purely adhesive type. The surface treatment (pickling) compared to degreased one, increases the shear resistance of bonded specimenswith epoxy adhesives, no difference was found for the specimen bonded with polyurethane adhesive.No significant

difference was found among the three different examined 6016 alloy finishes, both with polyurethane and epoxy adhesive.
The resuMs of the simulative test for crash evaluation, show a better behaviour for the CIBA XB53 15, in terms of absorbed energy, than the other one. The energy values were from four to ten times higher than those measured on the other adhesives.

Bondin~ of simule structural Darts.
The bonding cycle was defined and the nodes were bonded to the profile along four zones The adhesive (CIBA XB 5315) was chosen according to the result of previous

Bonding plus mechanical fastening .
In the shear tests the ultimate load found for bonded and clinched specimens, is higher than the clinched one and lower than the bonded one. In the pull tests the ultimate load found for the bonded p~us clinched specimens, is higher than the simple bonding one.
The results of tests carried out for the stiffness evaluation of bonded nodes, do not highlight any difference in X and Y direction between bonding and bonding plus cIinching one. From the crush tests results that the higher crashed heigths were found in the specimens bonded with polyurethane adhesive and the influence of clinch is higher for the simple omega specimens.
Three aluminium sheet with two adhesive layer are riot clinched easily with a 5 mm diameter but they can be riveted without problems for any diameter of rivet.

Assemblv mocedures
A frame was manufactured using four “T” nodes and extruded beams. The joining technique was the adhesive bonding plus mechanical fastening (clinching and riveting), No particular problems were found during the assembly operations. The accuracy of the frame was guaranteed by the precision of the extruded beams and the tolerances obtained from the stamping operation. The stiffness of the frame was calculated and some experimental tests developed. Under 1000 N load applied at a beam, the displacement of the frame was calculated about 5 mm on the opposite side of the load application point. The main deformation was found on the “ T “ nodes built with two stamped parts assembled by adhesive plus mechanical fastening.

- PSA

Mechanical fastening

Self piercing rivets appears as the best fastener in terms of mechanical properties (static and dynamic).
Clinching is an economical technology which can be easily controlled in a industrial environment. It is a convenient solution when requirements are limited and when the accessibility to joint area are good.
Bonding assistance give significant improvement for shear strength but not for pull strength and crush behaviour.

- Dairnler-Benz

Electron beam welding

Suitable electron beam welding parameters for a selected aluminium alloy combination were determined and defined. For the firstly tested overlap welding geometry a very low strength and brittle fracture behaviour was observed. After having changed to the butt welding geometry a sufficient strength and fracture behaviour was found. For demonstration purposes a structural sheet part reinforced with a strengthening cast insert was realized by electron beam welding. Despite of small problems due to thickness differences a good welding quality could be produced.

7. CONCLUSION

Sheet technologies

- Renault

Prototyping of large parts

- the forming realized show a best stamping behaviour of steel compared to aluminium.
- the design of the part and the tool must be adapted to aluminium.
- the influence of the mechanical properties shows that aluminium suppliers have to take that parameter in account in every further development for automotive industry.

- PSA

Tailored blanks

The feasibility of Alurninium Tailored Blanks has been demonstrated.
The industrial use of this technology is Iinked to the development of specific facilities to produce tailored blanks at a competitive price and with a high level of quality.

Profile technologies

- PSA

Dimensional forming of profiles

Forming processes are available to bend profiles according to the requirements of a space frame. Nevertheless, when aspect constraints occur, only very small bending are acceptable.

- Renault

Industrial approach of profile forming

Profile forming including 3D forming is technically solved. For industrial applications, the technico-economical analysis has to be precised including:

- production rate
- easiness due to the design
- assembling consideration
- in house policy of each company: equilibrium investment v.s. cost

Casting technologies

- Renault

Indirect Squeeze Casting

Mechanical properties of cast nodes are sufficiently high. The main problems are: geometrical accuracy for ISC and elementary cost of each node which has to be compensated by integration of function. Some profile type alloys can be used for cast nodes which will simplify the recycling problems.

- PSA

Thixocasting

The thixocasting provide high and promising quality parts. Nevertheless the process shows limits for thin walls parts and further developments are needed to have a totaIly reliable process.

- Volvo

Vacuum Pressure Die Casting

The potentiaI of casting complex closed box shapes offers a high degree of design freedom with the advantages of functions integration and reduced amount of joining in assembly Easy recycling since separation of cast nodes and profiles may not be necessary.
The investigated processes are used to their limits, geometrical and process-technical modifications are necessary but possible when the concept will face industrial production.

Joining technologies

- BMW

Spot welding

Within this part project, suitable welding tongs for aluminium are equivalent to a pedestaI machine have been developed. The main reasons for the relatively Iow number of spots with good quality (about 200 spots) are the very rapid electrode deterioration and the stil~ insufficient surface conditions of the aluminium sheets. Therefore these items need to be further improved in order to make spot welding for mass production more economical.

- Renault

Welding MIG TIG

Finally, on~y the MIG process is considered for profile/ cast joining, maximum gap of 1 mm is acceptable. WeIding speed of .8 m / : is realistic. Female nodes seem more convenient. Porosity of cast nodes is one of the key factors for achieving correct properties.
Pulsed MIG gives the highest properties in static. Fatigue properties were not studied in detail in this MABS project.
For profile / profile joining, a maximum gap of 1.5 mm can be accepted. Optimum welding design has been defined.

- PSA

Mechanical fastening

The different mechanical fasteners to be used have been defined with optimised parameters of realisation.
The comparison of several joining technologies in terms of behaviour and of constraint of application enables designers to choose the most suitable solution in each case.

- Daimler-Benz

Electron beam welding

Electron beam welding is an expensive but suitable joining process for special, safety critical components with high strength requirements. However, similar to other welding processes it is important to choose the right material combinations (simiIar ones) to prevent any generation of brittle phases. Electron beam welding is a high quality process which needs high quality joining partners such as cast material with low porosity and stamped or extruded parts with narrow tolerances. Another point which **has** to be taken into account is the importance to choose the best joining configuration for providing an optimal load transfer. Overlap welding may be very easy to handle with production conditions, but strength potential will be lost in this configuration.

Electron beam welding is a process which is suitable for welding components with high reliability and strength requirements. This weIding technique shall be used by suppliers which are specialized for production of the mentioned parts. However, electron beam welding is not suitable for mass production of car bodies due to high cost and long production times.

- **Opel**

General comments

The results in general have shown that aluminium in automotive industry can be used in different ways for simple components as well as for complete body concepts based on production numbers, manufacturing concepts and material cost.

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- Daimler-Benz

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- Volvo

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BMW

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9. REFERENCES

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