DRIVING FORCES FOR COST-EFFECTIVE COMPOSITES: NEW DEMANDS ON MATERIALS AND PROCESSES

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ABSTRACT

Material systems for mechanical applications are being developed under increasing cost pressure. Product development in the mechanical industries faces often conflicting and changing requirements. Decreasing system cost must be considered whilst maximising quality, functionality and return on manufacturing investment together with meeting legislative requirements for safety, emissions and recycling. In the automotive industry, weight increases from improved safety, refinement and functionality, interact with the vehicle mass reductions necessary to improve fuel economy and reduce emissions. The use of lightweight materials and construction techniques is becoming imperative. Driving forces for composites have changed, as viewed by OEMs, evolving from the 80's (CAFE standards, emissions, alternative fuels and electric vehicles) to the 90's (cost effectiveness, weight reduction, government initiatives, low volume vehicles) to the current increased demands of return on capital, safety and niche products. These are needed to drive developments in the next century. In the aerospace industry, the driving forces for weight reduction yielding improved range and reduced operational costs have always been apparent, but requirements for driving total cost savings are now a reason for change.

Steps towards weight reduction

Steps towards weight reduction in the automotive industry include improved steel, aluminum and magnesium technologies together with polymer composite materials. Several OEMs have developed light weight concept cars. For example, the Ford P2000 based on non-ferrous metals weighs 40% less than the steel equivalent, at 900kg. The UltraLight Steel Auto Body (ULSAB) concept reduced body-in-white mass by 25%. For composite materials to compete with steels and alloys, higher value must be added and cost reductions made in manufacturing cycles to balance the higher raw material cost. Target raw material prices to replace steel body-in-white are quoted (OEM figures) as $3/kg for aluminum, $4.4/kg for structural composites

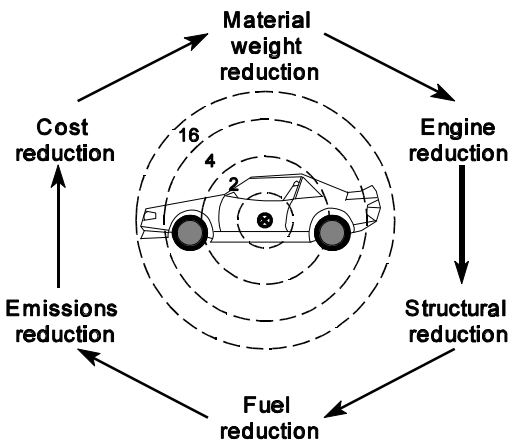

Fig. 1: Driving forces for a synergetic cycle with composites

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and $11/kg for carbon based composites ($0.9/kg for steel).

Current usage of composite materials

Currently the use of composite materials in the automotive industry is dominated by relatively low fibre content, random reinforced materials including SMC (150k tonnes/year) and GMT (77k tonnes per year) for exterior panels, under-bonnet parts and semi-structural sub-surface parts respectively. RTM and SRIM (10k tonnes/year) exhibit slow but steady growth for niche products and some increasingly structural items. While GMT and injection moulding technologies are relatively mature, there is intense interest in dedicated continuous fibre architectures (weaves, knits, etc). The improved properties arising from the higher and aligned fibre content offers potential in structural areas.

Reducing system cost

Carbon fibre composites, considered by several OEMs, have shown a 67% weight reduction over steel body-in-white structures, while a study by the Rocky Mountain Institute showed a 585kg vehicle yielding a fuel consumption of 0.8*l* to 2*l* /100km, compared with 3*l* /100km for a VW Lupo variant and 8.3*l* /100km for a 2.0*l* Ford Scorpio. Fig. 1 shows the advantages to be gained by reducing total vehicle mass to a level that is not currently possible in the metallic based industries. If a reduction in vehicle mass (specifically body-in-white) could be achieved, then a corresponding reduction in engine power would occur (needing lighter and smaller drive systems) thereby reducing the degree of structure required to hold the engine and hence the total cost of light weight materials. Composite materials would be highly synergetic in reducing vehicle energy use and pollutant production while increasing transportation efficiency. Daimler Chrysler will have invested $1.4 billion in fuel cell technology by the time their Necar 4 (A-class derivative) goes into production, or about the same as an entire line of profitable Chrysler vehicles. This fuel cell power train currently costs ten times that of an equivalent internal combustion system; with a target vehicle mass of 1320kg, weight savings would reduce power train output and hence cost. A concurrent approach is needed here; the development of light weight structures with advanced battery and fuel cell concepts to give a economic system.

A major concern is if these goals can be achieved while at the same time maintaining or increasing vehicle safety. Occupant deaths per million registered vehicles one to three years old (1995) were 75 for large utility vehicles compared with 250 for small cars, clearly justifying the driving force for increasing vehicle safety in the next decade, and extensive study on composite crash worthiness.

Major socio-political changes will be needed to bring about this carbon fibre based synergistic change, using recursive design and maximising mass decompounding (Fig. 1), to give what would essentially be a revolution in automotive engineering. For example, despite advances in internal combustion technology, the controversial CAFE standards have remained relatively static since the mid 80's. Given the required driving factors, huge shifts in the corporate policy and manufacturing philosophies of the major OEMs will be needed to accommodate this new class of materials for serious use. This will place a fierce demand on the composite industry that we should begin to address now to maximise future utilisation.

Current trends in cost effective composites

Current trends in automotive composite use are to gain added performance or value, at a reduced cost, requiring optimization of processes for high volume production. Given an anticipated increased usage of lean weight materials, developments are needed now in materials and processing science to play a key role in designing processing techniques for the future market.

An interesting question in the thermoplastic composites area will be the dominant matrix polymer used for structural components. Polypropylene based systems have shown wide application in GMTs and more recently in intimately blended systems (commingling and powder impregnation), but lack the compressive strength and heat distortion temperature for fully structural, cyclically loaded, applications. Examples of potentially interesting matrix systems are PET and PA12, but with the narrow processing window of PET currently thought to favour PA12 systems, provided that the economic conditions are satisfied.

For composites to be used in surface body-in-white areas, processes capable of producing a cost effective 'class A' finish are required. For example, a substantial percentage of a painted GMT component cost is related to the finishing system, indicating a large need for cost effective techniques to produce a class A surface. This will limit some processes to sub-surface applications and while unreinforced thermoplastic systems have been used for exterior surfaces, currently suitable reinforced systems are thermoset composites (SMC and RTM) or thermoplastic composites with polymer film overlays.

Maximisation of reinforcement efficiency

Several interesting routes for maximising reinforcement efficiency in composite structures have been developed. Traditionally, stiffness has been achieved either through design shape or the intrinsic properties of reinforcement, with a relationship between the two shown schematically in Fig. 2. To overcome the limitations of these techniques, a synergy of the intrinsic stiffness of aligned fibre structures and the geometrical stiffness of bulk composite flow processes is required. Four processing avenues to increase added value have been identified:

1) Adapted preform flow moulding
2) Drapable preforms - polymer/reinforcement fibre mingling
3) Liquid moulding with intelligently designed fibre architectures
4) Material and process integration

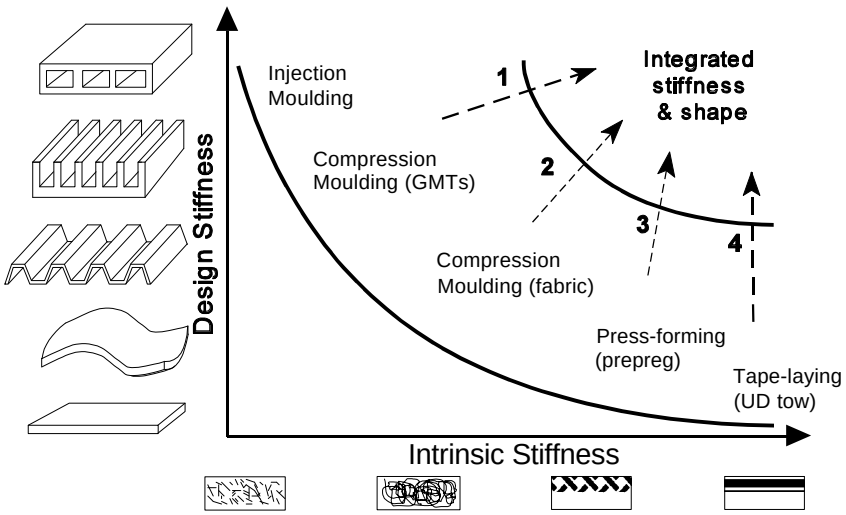

Fig. 2: Adding value to materials systems through intelligent combination of stiffness

Adapted preform flow moulding is considered as the formation of sandwich structures utilising flowable cores of GMT or LFT type short fibre thermoplastic systems (geometric stiffness) with skins of woven or knitted commingled yarns. This offers increased specific flexural strength at the sandwich location together with the ability to locally place preforms of aligned fibre materials where needed in the structure. This increases the design freedom and reinforcement efficiency of the industrially accepted GMT process while still using commodity glass and polypropylene raw materials. The existing processing infrastructure can be utilised, easing implementation of increasingly structural composite systems into the market.

The recent introduction by several manufacturers of affordable intimately blended systems that can be woven and knitted into the conventional range of drapable fabric products has opened new areas of the vehicle structure to composites. Here the intention is to mimic the steel stamping and manufacturing process, with non-isothermal stamping of commingled fabrics at forming rates of 200mm/s, consolidating thin shelled parts. This would move away from component integration towards simplicity, with conventional shell welding techniques being adapted to the thermoplastic materials. Automated materials handling (preform preparation, heating, transfer, pinching, removal) together with automated scrap handling is reported as requiring further work before high volume implementation.

Conventional liquid moulding techniques, where a dry fibre bed is impregnated with a matrix polymer, have the potential to increase raw material efficiency by integrating intrinsic stiffness with a degree of shape complexity. Previous disadvantages of fibre preform waste have been addressed by the P4 process (programmable powered preform process), developed by Owens Corning. Using a robot equipped with a chopper, glass fibres and a binder are sprayed onto a perforated screen (having the same geometry as the moulding tool), with air sucked through the screen to hold the glass in place. Cutting of fabric is eliminated, reducing waste and creating a net shaped preform. Other techniques to increase reinforcement efficiency under large scale study (matching local fibre direction to principle loads) including embroidery and directional weaving techniques to create net shaped preforms.

A limitation of thermoplastic processing has been the high melt viscosities of the polymers (10^2 to 10^4 Pa.s), addressed to date by intimate blending techniques, reducing mass transfer distances during impregnation. Thermoplastic RTM is also under development, with two prominent systems available, a PET 'cyclic system' and the anionic polymerisation of lactams (polyamide 12). By injecting a low viscosity activated thermoplastic monomer directly into a fibre bed (as with thermoset RTM) which polymerises in situ, thermoplastic RTM can be performed. Thermoplastics offer a number of advantages over thermoset systems including a general toughness increase, remoulding of recycled scrap, and numerous post forming possibilities. However, given the low current economic incentive for recycling, such systems must be cost competitive with thermoset systems in todays market. Compression moulding based technologies require increasing press tonnage and tooling cost with increased size, to date limiting the size of commercial applications. Future application of composites to body-in-white structures may show economic advantages for large structures where several low pressure RTM lines operate in parallel. Preforming techniques under development for thermosets can naturally be applied to thermoplastic RTM.

For any composite application, it is vitally important to design for the processing technique, using the specific advantages in the most effective manner. Previous work has combined steel stampings with over-injection moulding, developed by Bayer and used in a OEM front carrier assembly. This has been taken one step further by integrating composite and polymer processes in a manufacturing cell to create an all polymer system. Recent work has focussed on maximising design freedom and shape stiffness by

combining bulk composite flow moulding processes with UD tows or commingled fabrics of high intrinsic stiffness. This is considered to open new perspectives in polymer and composite design and processing. Optimisation in a manufacturing cell of tow or fabric temperature results in interfacial healing with the over-injected polymer, combining in a net shaped part cosmetic function with a structural member. Cycles times for parallel configurations are limited only by injection moulding cycle times.

Future use of composite materials

Future applications will use a combination of composite techniques together with advanced steels, aluminium and magnesium materials. The true advantages of composites will not be realised until the vehicle design is optimised to use the full advantages of specific materials and processing routes and the driving force exists to bring about a change in OEM philosophy.

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