Advanced materials of automobile bodies in volume production

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Abstract

Nowadays even regular drivers informed about application of high strength and low density materials in automobile structures. The reasons for it are not only intention of automobile manufacturers to redivide a market for their benefits or advertising purpose, but adequate response to legal requirements regulating fuel economy growth and protection of environment. Aluminum automobile bodies, nonmetallic closures and interiors made of natural materials are emerging on roads and city streets. However all these novelties are results of invisible but tremendous efforts of scientists, designers, product engineers, metallurgists, economists and marketing experts. If management decision of material selection is not based on deep analysis, then negative economic and technical effect are matters of course. Development onrush of traditional and alternative body materials complicates this decision even for expert. Material selection for automobile body and related technical, economical and geographical details are outlined in the present paper. Latest advantages of metallurgy, polymer and composite manufacturing as well as safety, repair and recycling issues are briefly analyzed from automobile engineer standpoint. A number of scientists and technicians could be interested in collaboration programs between automobile, metallurgical, academical and government organizations oriented to developing of advanced body designs and materials, so most prosperous of them are described below. Analysis of modern automobile designs is given on the basis of all these data; moreover, forecast of future progress is completed. Attempt to cover all variety of up-to-date body materials, analyze and highlight the most promising of them for volume production was committed on small scale of the paper.

Keywords: light weight material, material selection, automobile material, automobile trend.

Abbreviations

ABS – Acrylonitrile Butadiene Styrene
AHSS – Advanced High Strength Steel
AISI - American Iron and Steel Institute

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BEV – Battery Electric Vehicle
BH – Bake-hardening Steel
BIW – Body-in-white
BMC – Bulk Moulding Composite
CAFE - Corporate Average Fuel Economy
CFRP – Carbon Fiber Reinforced Plastic
CM – Carbon-Manganese Steel
CP – Complex-phase Steel
DP – Double-phase Steel
ECV – Experimental Composite Vehicle
EISA - Energy Independence and Security Act
EuroNCAP - European New Car Assessment Program
FCV – Full Cell Vehicle
FreedomCAR - Freedom Cooperative Automotive Research
FRP – Fiber Reinforced Plastic
FSV – FutureSteelVehicle
GFRP – Glass Fiber Reinforced Plastic
HS IF – High Strength Interstitial Free Steel
HSLA – High Strength Low Alloy Steel
HSS - High Strength Steel
ICE - Internal Combustion Engine
IF - Interstitial Free Steel
IISI - International Iron and Steel Institute
LCA – Life-Cycle Analysis
MILD – Mild Steel
MS – Martensite Steel
PA – Nylone
PC – Polycarbonate
PE – Polyethylene
PEV – Plug-in Electric Vehicle
PNGV - Partnership for a New Generation of Vehicles
PP – Polypropylene
PPO - Polyphenylene Oxide
PU – Polyurethane
PVC - Polyvinylchloride
RRIM - Reinforced Reaction Injection Molding
RTM - Resin Transfer Moulding
SMC – Sheet Molding Compound
SS – Stainless Steel
TRIP – Transformation Induced Plasticity Steel
TWB – Tailor Welded Blanks
TWIP – Twinning-Induced Plasticity steel
UHSS – Ultra High Strength Steel
ULSAB - Ultra Light Steel Auto Body
US DOE – United States Department of Energy

1. Introduction

Automobile body puts into life artistic skills and aesthetical insight of art-designer along general technical erudition and intimate technology knowledge of engineer-technician. Though, as a rule, consumer is more concerned with appearance, ergonomics and comfort. At the same time, automobile engineer notices modest technical performance of structure.

Undoubtedly, key factors of automobile volume production are cost, safety, volume production suitability and universal repairability. Furthermore, different problems appeared in distinct phases of automobile history and their solutions often had an impact on body design. In such a way, in postwar 1950s exhausted Europe restrained consumption of steel reducing automobile manufacturing (Foy, 2013). Many efforts undertook against corrosion occurrences in 1960-1970s, especially in the North-East of the USA, Canada and Europe. Governments concentrated on fuel economy after oil embargo of the Organization of Petroleum Exporting Countries against Israel allies in the October war of 1973 resulting in 4-time oil price leap and Iran revolution of 1978-1979 resulting in 2-time oil price leap (Hamilton, 2013). In 1990s European Automobile Manufacturers Association promoted ecological standards Euro inducing emission reduction of exhaust gas. In 2000s safety standards developed according to European New Car Assessment Programme (EuroNCAP) in spite of real resistance of automobile manufacturers (Hobbs and McDonough, 1998).

At the present time stable steel production and modern corrosive-resistant body materials allowed announcing 12 years warranty against penetration (Davies, 1993). But fuel economy and protection of environment issues still engross minds of government organizations, corporations and customers. Emergence of alternative automobile power units, metallurgy and plastic fabrication successes, uprising of novel structures and technologies – all of these generate variety of problem solutions.

For instance, enforcing Corporate Average Fuel Economy law (CAFE), which adopted in 1975, leads decreasing of automobile weight, popularization of fuel efficient cars and acceptance of electromobility concept (Klier и Linn, 2012). The Energy Independence and Security Act of the USA (EISA) passed in 2007 and looks forward to next fuel economy spurt by 2020. However demand for powerful engines, oversized and off-road automobiles is not descending in the USA. Moreover, Cooman et al. (2011) showed amazing growth of average curb weight up to 90% in Europe since 1970 to 2010! Therefore weight decreasing issue is a still contradictory and hotly debated matter.

Euro ecological standards are widely used in the EU and out of borders. The UN Climate Change Conference (Mexico, Cancoon) in 2010 emphasized arising interests of the EU and the USA in environmental protection relating to automobile transport. Let us consider that the USA is one of few countries that have not ratified Kyoto Protocol to the UN Framework Convention on Climate Change. Moreover, the UN Climate Change Committee (2010) informed that correlation between carbon dioxide in atmosphere and climate change is still not clearly established. Recent research of Russian ecologists showed that contemporary emission of carbon dioxide and nitrogen oxides has secondary contribution among other greenhouse gases (Fedorov et al, 2011). But nevertheless due to some unclear reasons developed countries push ambitious environmental laws, for example, the UK adopted the Energy White Paper in 2003 to achieve 60% reduction of CO_2 emissions by 2050 (Harwatt et al, 2011). After all, such careless spending of budget funds seems wasteful.

Interestingly, automobile transport is a prevailing source of air pollution by nitrogen and carbon oxides, hydrocarbons, but it is correct for urban ecology only. Moreover, simple, but consistently observed actions in traffic regulation, public transport organization, road and city infrastructure can sufficiently decrease vehicle emissions both urban and overall (Singh, 2012). In worldwide and national scales fuel end energy sector and heavy industry confidently dominate among other artificial air contaminants (Fedorov et al, 2011). It becomes apparent that popularization of electric cars cannot resolve emission problem, but inflict it to other industrial sectors. Hence reasons of ecological laws enforcing is unclear from industrial ecology standpoint.

Here are basic fuel economy factors of automobile design: 1) aerodynamics; 2) rolling resistance of tyres; 3) weight; 4) drivetrain efficiency; 5) optimum operating point of engine; 6) ancillary equipment; 7) intermittent engine shutdown; 8) waste energy exploitation. There is a belief that fuel economy improvement follows the rule: weight decrease of 10% results in fuel economy of 6-7%. In such a manner fuel economy and emission concerns stipulate weight decreasing projects. Modern body-in-white (BIW) takes nothing less than 20% of gross vehicle weight (by the example of 1400 kg vehicle) as in the fig. 1. And body consumes 63% of total usage of mild low-strength sheet steel in automobile (by the example of an average European van). For this reason a huge weight decrease opportunity is in high strength steel development and light materials research.

One can make a personal contribution to fuel economy and environmental protection, if purchase an electric car instead of a regular one with internal combustion engine (ICE). However short range, small speeds, low development of service and charge infrastructure and price exceeding $17000 per average European electric sedan allows traditional design car manufacturers to have a regular income. Though a question appears, will tremendous effects in body weight decrease made if light, effective and cheap electric car cells suddenly emerge (Davies, 2012)? Well, such technical knockout definitely could herald electric power era. But, unless this happened, designers adapt strength structures for heavy cell stacks and batteries to traditional external body concepts and develop crash protection of automobile electrical systems.

2. Materials

Most common material of both body structures and whole automobile manufacture is steel. History of automobiles explains this state of things. The USA being an absolute leader of automobile industry in 1920s shifted from manual to line production, at that almost all variety of materials was replaced by sheet steel. Ideologist of automobile conveyer production, manufacturer Ford Motor Company (Detroit, the USA) and body details supplier Budd Company (Troy, the USA) favored low carbon steel because quick press forming of panels from flat blanks and appropriate resistance welding technique were very attractive for mass production (Ford, 1922). By the way it beneficially increased body torsional stiffness (Davies, 2012). This trend propagated to their allied companies Ford Dagenham (London, the UK) and Pressed Steel Company (Oxford, the UK) in the Europe. Likewise steel became a prevailing material of automobile body manufacture. Steel hegemony was immovable till 1970s, when laws for fuel economy, environmental protection and safety were adopted and interest of automobile companies to light materials was sparked. Nowadays aluminum, magnesium alloys and polymers are most advanced for automobile industry.

2.1 Steel

There are a lot of papers about light materials research completed in last 30 years, but majority of car owners drive essentially steel vehicles. This material has following advantages: 1) versatility; 2) low cost; 3) stable supply; 4) high formability; 5) high impact resistance; 6) wide hardening ability; 7) good corrosion resistance of coated steel; 8) assembling simplicity; 9) reforming possibility in manufacturing and service life-cycle stages; 10) well-developed repair and maintenance technology; 11) fine recycling. Here are main disadvantages: 1) high density; 2) corrosion susceptibility of uncoated steel (Arzamasov et al, 1990).

Steel versatility appears due to vast variety of grades. Automobile steel types and their ultimate strength and elongation properties are shown in fig. 2. Conventional steels are represented by types: mild steels, rephosphorized steels, bake-hardening steels, isotropic steels, carbon-manganese steels, high strength low alloy steels.

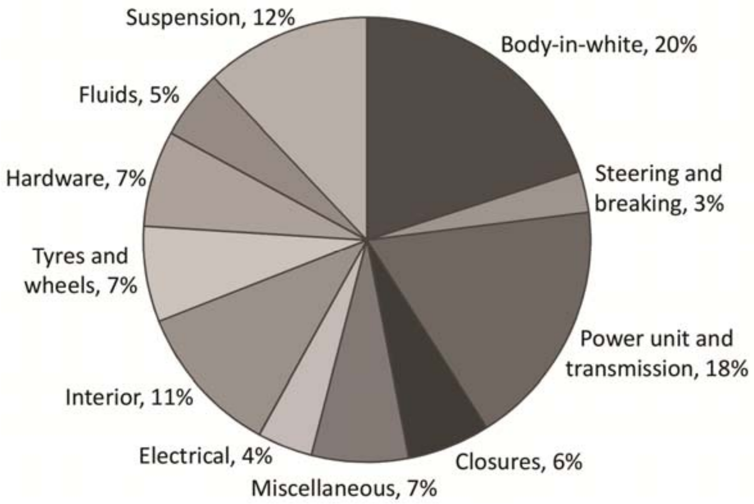

Figure 1: Contribution of BIW to weight of 1400 kg automobile (as % of curb weight)
Source: Hatch-Europe

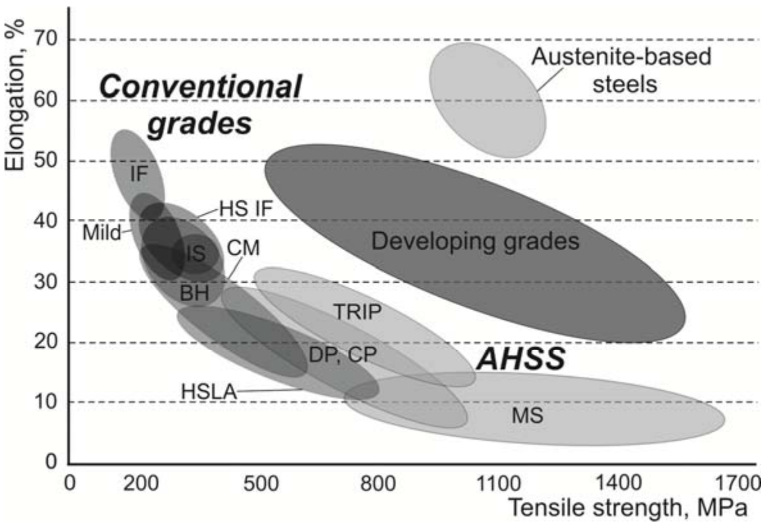

Figure 2: Tensile strength and elongation of automobile steel types
Source: WorldAutoSteel

Mild steels (MILD) have predominantly ferrite microstructure that specifies low yield limit (from 140 MPa). Extrusion steel and aluminum-killed steel are typical MILD that have extensive use in mass production.

Rephosphorized steels have ferrite basis with ferrite phosphor-riched grain layers. Ferrite gives plasticity, and phosphor-riched grains increase strength. Fine formability, covering and painting simplicity, improved corrosion resistance are typical features of this steel type.

Interstitial-free steels (IF) have plenty low carbon content (less than 0.005%). Besides, IF undergoes vacuum degassing that releases carbon, oxygen and nitrogen interstitial atoms as distinct from MILD. This procedure obstructs dislocation motion and, thus, improves formability, decreases dent resistance and strength. IF has lower yield limit than MILD and the same strength, hence this type is more preferred for deep extrusion and stamping.

High strength interstitial-free steels (HS IF) have high formability conditioned by ferrite matrix and increased strength determined by phosphor, silicon, manganese, carbides and nitrides additives and fine grain structure. Yield limit of HS IP usually exceeds 210 MPa.

Bake-hardening steels (BH) have 2 hardening mechanisms: 1) strain hardening caused by cold stamping; 2) bake hardening due to fine dispersed hardening phase separation during metal heating within bake furnace after product painting (usually at 150-200 ºC). There are a lot of carbon in solid solution after anneal that admits dislocation motion after strain hardening. Dislocations are fixing during baking, thus strength and dent resistance grows.

Isotropic steels (IS) have fine grain ferrite microstructure. Their main feature is independence of strength and strain properties from loading direction.

High strength low alloy steels (HSLA) have high strength owing to fine grain structure and microalloying elements that provoke carbides precipitation and, consequently, arrest dislocation motion and increase yield limit (Savkin et al, 2013).

Automobile engineers are interested in advanced high strength steels (AHSS) and desire to achieve great energy absorption of vehicle structures and five-Star EuroNCAP rating. Initially preconceived attitude to AHSS was normal because it was thought that plasticity is more important than strength for sheet steel. First grades had redundant properties instability and tool wearing reputation. Recently the International Deep Drawing Research Group completed design and material selection recommendations for wear-resistant tools, and these problems became things of the past. Nevertheless attempt to stamp HSS using old equipment certainly leads to scrap amount increase and reforming necessity. HSS are usually using for longitudinal intrusion beam (for front and rear impact energy absorption), B and C post, roof ribs and door apertures (for side impact energy absorption). AHSS demand in automobile manufacture is high enough, so metallurgists develop new HSS steel grades. According to AISI report, AHSS consumption grew up more than in 3 times in automobile industry since 2006 to 2010 (Carabba, 2013).

In some countries, in the USA for instance, AHSS development has official government approval. In 2006 following body weight decrease purposes the United States Department of Energy (US DOE), National Steel Fabrication, American Iron and Steel Institute (AISI) and Auto/Steel Partnership at the seminar “Advanced HSS Workshop” (Arlington, the USA) decided to promote AHSS third generation. Desirable properties range alters since 600 to 1600 MPa for ultimate tensile strength and since 20 to 40% for elongation correspondingly. Key universities also participate in this program. It is expected to develop of low carbon (weldable), cheap (cheap alloying additives) set of steel grades compatible with existent forming, assembling and repair equipment. Moreover chemical composition limitations are present and high quality product surface is required (Davies, 2013)

Here are typical AHSS classes: double phase steels, multiphase steels, transformation-induced plasticity steel, twinning-induced plasticity steels, martensite steels.

Double phase steels (DP) usually have ferrite matrix and martensite phase created by alloying and heat treatment. High strain hardening rate is a result of formation and dislocation galling around martensite fraction during straining. DP steels have bake-hardening ability as BH. High strength and reasonable high elongation combination produces vast area under monotonic stress-strain curve, consequently, high impact resistance even in comparison with HSLA. Set of alloying elements provides fine steel weldability. Though, DP show detrimental tendency to edge cracking due to microcracks on ferrite and martensite phase interfaces.

Transformation-induced plasticity steels (TRIP) feature metastable austenite transformation to martensite during strain hardening. TRIP have ferrite matrix and dispersed inclusions of strength martensite and (or) bainite phase. Amount of retained austenite is regulated by manganese and carbon content. TRIP have high impact strength and fatigue durability, therefore they come into use in intrusion beams, crossmembers, B and C posts, bumper reinforcements.

Twinning-induced plasticity steels (TWIP) properties apparently depend on stacking fault energy of crystalline lattice and local stress concentration conditioning character of Hall-Patch effect that allows to obtain desirable austenite phase transformation (Dieter, 2013). TWIP are high-manganese steels (up to 30% of manganese) and they remarkably combine IF plasticity and TRIP strength. However, there are still problems with hydrogen embrittlement of deformed regions, welding technology issues and low compatibility to mass production. From the scientific standpoint, physical metallurgy of TWIP still insufficiently investigated, including twinning mechanism, structure evolution and delayed fracture phenomena (Cooman et al, 2011). TWIP are developing mostly for energy absorbing structures, but they are under testing in engine industry at the present time. Last 10 years interest to TWIP is incredibly high (Pla-Ferrando R. et al, 2011).

Complex phase steels (CP) are usually hot-rolled, fine-grained steels with small amount of martensite, retained austenite or perlite in ferrite/bainite matrix. CP usually more plastic and have strength of DP.

Martensite steels (MS) are hot-rolled steels with extremely high strength properties. Austenite exists during hot rolling and anneal and almost fully transforms to martensite during tempering on run-out table or in cooling section (in case of continuous anneal). MS have small amount of ferrite and (or) bainite in martensite matrix. Retained austenite portion is smaller in MS than in CP.

Stainless steels (SS) have a position apart from other steel types. Chrome additive creates oxide film on SS surface and protects it from corrosion. Advantages of this type are corrosion resistance, fine formability, and excellent adaptation to manufacturing infrastructure of mild steel. Chromium nickel (ASTM 3xx) and chromium ferrite alloys (ASTM 4xx) have the greatest usage in modern automobile industry among other stainless steels. So, SS are suitable for parts that undergo aggressive corrosion and (or) high temperature effects, for example, turbocharges (310), exhaust system (304(L), 409) and fuel tanks (304(L)). But one can find SS in decorative body parts too, for example, in doors, posts, bumpers, handrails and wheel caps (304(L), 316(L), 430, 434, 436) (Borodulin and Moshkevich, 1973). ASTM 409 is the cheapest grade and thus it is popular in automobile mass production. In these latter days SS are adapted for load-carrying structures. Next Generation Vehicle program (2005-2007) joined together efforts of car manufacturers Audi, BMW, Fiat, Daimler, Saab Automobiles, Volvo Car and metallurgy companies ThyssenKrupp and ArcelorMittal Stainless Europe to create new stainless steel grades and develop effective designs made of them (Schubert et al, 2008).

As a result of collaboration austenite SS EN 1.4376 (UNS S20100), 1.4318 (S30153), 1.4310 (S30100) and DP complex alloyed steel 1.4162 (S32101) was approved for B-post and floor reinforcements (Schedin et al, 2008). Moreover, painting of internal parts of stainless spaceframe is optional. Unfortunately, SS are expensive, have high density and supply sources are limited.

There are given available HSS in the EU market and some their properties in table 1.

Despite certain steels recently emerged, forming steels are not prevalent today. This fact is illustrated in fig. 3. The diagrams shows change of automobile engineers preferences from MILD to HSS and CP. Increase of DP share (up to 30%) and UHSS appearance (up to 8%) is a typical feature of last decade. Also there is a change of BMW choices to HSS attributed to weight decrease efforts in fig. 4. Rise of HSS share (up to 30-50%) is evident, mostly owing to BH steels (Ludke, 1999).

2.2 Aluminum

Over a XX century aluminum was rarely used, expensive and lightweight alternative in automobile mass production in preconveying 1900s, for example in Pierce-Arrow, and in postwar 1950s, in Land Rover (Foy, 2013). Such position can be explained by high material cost, double body assembly cost, worse weldability and formability than steel. Aluminum requires specific equipment for welding, cold forming and painting (Rubinchik, 1974). Aluminum strain hardening may cause low-cycle fatigue initiation. Aluminum elastic modulus is 3 times less than steel elastic modulus, and since stiffness has prior effect on design thicker gauges are indispensable. Nevertheless, as occurrence of Audi aluminum spaceframes exhibited, approved mass manufacture eliminates technological issues, but cost question is still unsettled. Fortunately, aluminum has outstanding advantages: 1) aluminum body is 2 times lighter than regular steel body; 2) high corrosion resistance offers savings due to optional nature of covering and painting; 3) aluminum recycling is not a problem; 4) scrap costs up to 50% of primary aluminum (15% is for steel). Common automobile aluminum alloys are given in table 2.

The most famous aluminum consumer among automobile manufacturers was Land Rover until recently. So aluminum-manganese (AA 3xxx) and aluminum-magnesium alloys (5xxx) were applied for Defender for a long period. Nowadays there are preference to aluminum-magnesium (5xxx) and bake-hardening aluminum-magnesium-silicon alloys (6xxx).

Table 1: High strength steel available in the EU

Steel type	*Yield stress, MPa*	*Hardening mechanism*	*Standard*
MILD	140-180	Residual interstitial atoms C, Mn, Si	EN 10130
Rephosphorized steel	180-300	Solid solution hardening	PrEN10xxxx EN10292
IS	180-280	Additives Si	PrEN10xxxx
BH	180-300	Strain aging	PrEN10xxxx EN10292
HSLA	260-420	Grain refinement and precipitation hardening	
DP	450-600 (ultimate stress)	Martensite phase in ferrite matrix	
TRIP	500-800	Transformation of retained austenite to martensite during straining	PrEN10xyz
CP, MS	800-1200	Bainite and (or) martensite phases, induced by thermal treatment	

Source: Davies G. (2012) *Materials for Automobile Bodies*

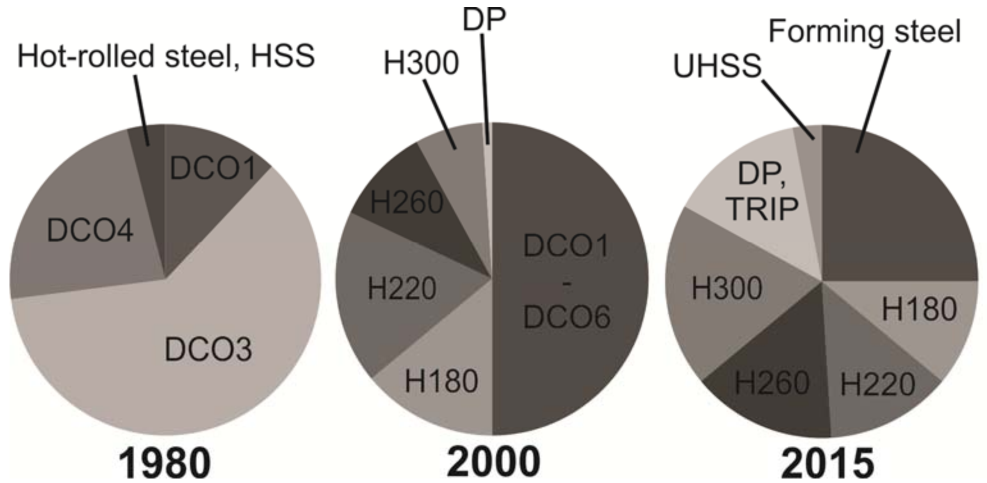

Figure 3: HSS consumption share growth in automobile industry
Source: Davies G. (2012) *Materials for Automobile Bodies*

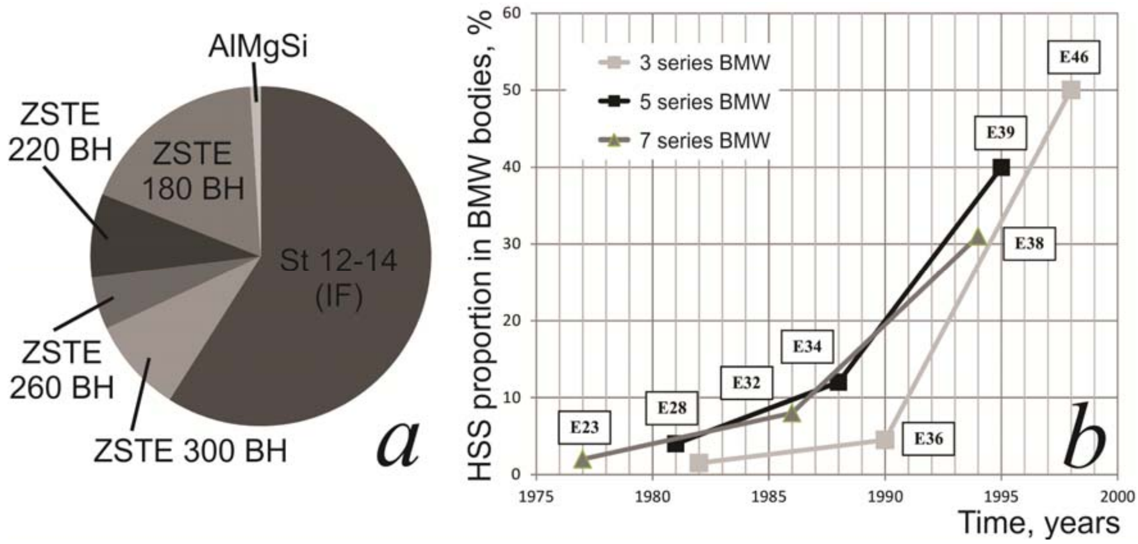

Figure 4: 4a – Steel proportion BMW 5 body, 4b – HSS share growth in BMW body
Source: Ludke B. (1999) Functional Design of a Lightweight BIW Taking the New BMW Generation as an Example

5xxx aluminum alloys are reasonable cheap (however, in 3 times more expensive than covered steel), have small strength, but fine formability, weldability and corrosion resistance. Bake hardening is not feasible. Tend to form Lueders striation lines is main disadvantage of this alloy series. These defects have the appearance of waved coarse strips (A type) on the sheet surface and they appear during material yielding. Fortunately, several alloy tempers developed that fully exclude they occurrence. B type Lueders lines can also appear during stretch flattening. They don't have any effect on reliability, but impair product appearance. In spite of run-in and hot treatment, Lueders lines appear during forming and can be observed through paint layer. For this reason 5xxx alloy usually are not in use for external panels (Hatch, 1984).

Aluminum-magnesium-silicon alloys (6xxx) have higher yield limit that 5xxx alloys. Heat treatment is available, including hot drying. Aluminum-magnesium-silicon alloys (in particular, 6016) are universal and they are mostly frequently used in European automobile industry among other aluminum alloys due to outstanding combination of elongation, dent resistance and surface constancy. Strength properties of 6xxx alloys are medium, cutting ability is satisfactory. Though aluminum-magnesium-silicon alloys are in 5 times more expensive than covered steel, hence they are usually applying for external panels only.

Last advances in automobile aluminum alloys (table 3) include appearance 6181A and 6022 with higher strength than 6016, which means improved formability and hemming. 2036 alloy was adapted in the USA for hoods with 0.8 mm thickness, but due to recycling problems it is not popular in the EU despite supply of 2036 is better. The most advanced aluminum alloys in aerospace industry are aluminum-lithium alloys that combine high strength-weight and modulus-to-density ratios. They are heat formable, have excellent strain hardening and cutting ability. Third generation of aluminum-lithium alloys with decreased content of lithium appends, though main usages of them are fuselages of aircrafts and helicopters (Prasad et al, 2014). High cost still restricts usage of these alloys in automobile mass production (Luts and Suslina, 2013).

2.3 Magnesium

Magnesium is the lightest engineering material; its density at 35% smaller than aluminum and 4 times smaller than steel. High-purity magnesium alloys (for example, AZ91E) with minimal metal inclusions content (iron, copper, nickel) have great corrosion resistance. These properties are applied in aircraft industry for gear-box case castings of helicopter McDonell Douglas MD500. Magnesium alloys have usage in automobile industry also, for example for engine bracket of Chevrolet Corvette (AM60B) and front-end of Jaguar XJ351. High cost of magnesium alloys evidently makes them not attractive for mass production. Moreover there are no flat production and extrusion technologies. Magnesium is chemically active, tends to creep, requires anticorrosive coat and has small melting temperature. Ghassemieh (2011) proposed to use AE42 that indisposed to creep and corrosion or cheaper magnesium alloys with rubber coating as aluminum alternative in body structures.

Despite on all these disadvantages Davies (2013) suggests manufacturing application of AZ191 (ultimate stress 240 MPa, yield limit 160 MPa, elongation 3%), AM60 (ultimate stress 225 MPa, yield limit 130 MPa, elongation 8%), AM50 (ultimate stress 210 MPa, yield limit 125 MPa, elongation 10%) in addition to aluminum to develop distinct automobile parts in the short-term period (table 4).

Table 2: Modern automobile aluminum alloys

Alloy AA DIN	*AA6016 AlMg0.4Si1.3*	*AA6111 AlMg0.7 Si0.9Cu0.7*	*AA6009 AlMg0.5 Si0.8CuMn*	*AA5251 AlMg2 Mn0.3*	*AA5754 AlMg3*	*AA5182 AlMg5Mn*
Temper		T4		H22	O/H111	
Ultimate stress, MPa	210	290	250	190	215	270
Yield stress, MPa	105	160	130	120	110	140
Elongation, %	26	25	24	18	23	24
r	0.61	0.55	0.64	-	0.7	0.8
n 5%	0.3	0.28	0.29	-	0.35	0.33

Source: Davies G. (2012) *Materials for Automobile Bodies*

Table 3: Automobile aluminum alloys under development

Alloy AA DIN	*AA6022 AlMg0.6Si1.3*	*AA6181A EcodalR-608 AlMg0.8Si0.9*	*AA5022 AlMg4.5Cu*	*AA5023 AlMg5.5Cu*	*Pe-600*
Temper	T4		O/H111		
Ultimate stress, MPa	270	230	275	285	270
Yield stress, MPa	150	125	135	130	140
Elongation, %	26	24	28	29	
r	0.6	0.65	0.7		0.72
n 5%	0.26	0.28	0.34	0.36	0.34

Source: Davies G. (2012) *Materials for Automobile Bodies*

Table 4: Common automobile magnesium alloys

Alloy	*AZ181*	*AM60*	*AM50*
Chemical composition			
Al, %	9	6	5
Zn, %	0.7		
Mn, %	0.2	0.3	0.3
Mechanical properties			
Ultimate stress, MPa	240	225	210
Yield stress, MPa	160	130	125
Elongation, %	3	8	10

Source: Davies G. (2012) *Materials for Automobile Bodies*

2.4 Polymers, plastics and composites

Polymers have a lot of advantages: 1) manufacturing simplicity of complex part; 2) easy assembly; 3) negligible damage after low-velocity impact. Though there are a lot of specific claims to automobile polymers. For instance, polymer must withstand cabin temperature within the range of -40 to 90 ºC. All these requirements could be separated into divisions: 1) Thermoplastics have low elastic modulus (3GPa) and often low strength. Thus improvement of the properties is still relevant. 2) Polymers must exhibit fine impact resistance under both low and high-velocity impact. Composites meet these cases, but prediction of fragment distribution and retaining of segregated parts after impact is a new untypical for metals problem. 3) Polymers tend to have higher thermal growth than metals, which can result in buckling, distortion and backlash roughness. Design usually considers this feature. 4) Chemical resistance of polymers is crucial because they tend to degrade, for example, due to contact with fuel. Inhibitors additives sometimes remove this lack.

Thermoplastics and thermosets are typical polymers in common use in automobiles. Thermoplastics are high molecular materials, which soften and melt on the heat application. Various thermoplastics are composite components with high, but directional strength, low weight, corrosion resistance, fine thermal properties.

Thermoplastics can be divided into amorphous and crystalline varieties. Molecules are oriented randomly in amorphous forms. Typical amorphous thermoplastics include polyphenylene oxide (PPO), polycarbonate (PC) and acrylonitrile butadiene styrene (ABS). The advantages of this group include: 1) relatively dimensional stability; 2) lower mold shrinkage than crystalline forms; 3) potential for application as structural foams. The disadvantages include: 1) fast wear abrasion; 2) low fatigue resistance; 3) increased process times compared to crystalline thermoplastics. Crystalline thermoplastics have regions of regularly orientated molecules. Examples include nylon (PA), polypropylene (PP) and polyethylene (PE). Here are some advantages of this group: 1) good solvent, fatigue and wear resistance; 2) higher design strains that amorphous grades; 3) high-temperature properties improved by fiber reinforcement. Disadvantages of crystalline thermoplastics include: 1) high and variable shrinkage; 2) poor adaptation to adhesive bond; 3) higher creep than amorphous thermoplastics.

Thermosets are more brittle than thermoplastics so they are usually used with reinforcement materials. Advantages include: 1) lower sensitivity to heat than thermoplastics; 2) good dimensional stability; 3) higher hardness and scratch resistance than thermoplastics. Disadvantages: 1) low toughness in fracture; 2) complicated recycling; 3) low surface finish. Recycling is still main problem during vehicle disposal because polymer parts almost inevitably remain in shredder fluff and end lives in landfills (Kroes et al, 2010).

Despite polymers seem pioneer materials they found application in Chevrolet Corvette as early as 1953. Production method is very important for composite materials and it depends on technical requirements and cost. Commonly known prepreg method consist in coverage of carbon or glass fibers in cloth framework by epoxy resin, but it is suitable for restricted number of automobile parts due to high volume production. One of the greatest obstacles in high volume production is prolonged interval of preliminary pressure shaping when fibers occupy correct position with assigned orientation. This technological process means long production time, expensive labor force and low machine effectives which are incompatible with high volume production. Following composites made of thermosets are widespread in automobile industry: 1) sheet molding compound (SMC), bulk molding compound (BMC), reinforced reaction injection molding (RRIM) and resin transfer molding (RTM). SMC and RRIM are the most popular and they have 48% and 40% of worldwide thermosets consumption in automobiles in 2000 (Ghassemieh, 2007).

Environmental concerns induced a concept of using cheap natural fiber materials in automobile body. In the past decade many European car manufacturers tested these materials for door panels, seats, internal roof boards, fascia and interiors. Composites based on kenaph, hemp, linen, jute and sisal fibers appear reasonable good. Patel et al showed in 2002 that energy absorption of composite panel with linen fibers reaches 17% of GFRP absorption level. Ambitious development is carrying out in polymerization and crystallization research, matrix-to-fiber bonding and improvement of water repellency and fire resistance.

3. Collaborative development programs

At present time many collaborative development programs oriented to automobile light weight design and material development. Success of these programs often stands on interaction between private and (or) public companies, which allows research light materials and investigate effective designs and innovative technological solutions. These projects often lobby interests of material manufacturers, but sometimes they emerge as industry response to passed law. Certain programs initiated by vehicle manufacturers through in-house modernization program. The most famous projects are described below.

3.1 ECV and ASF

Experimental Composite Vehicle (ECV) is a research program of alternative body materials (foremost, aluminum) oriented to improve fuel economy and general performance. The program was launched by British Leyland in 1982 as response to fuel shock in 1970s. Technical support entrusted to Alcan.

First target was creating automobile mass production with using of alternative materials. Austin Rover Metros was accepted as model under research. Precoated panels of aluminum 5251 alloy were proved and its adaptation to existing stamping equipment was revealed. However attempt to reach surface finish quality equivalent to steel was failed. Manual welding was applied, but robotic welding was guaranteed for real needs. Second phase included prototyping of 5 Fiat X1/9s, 2 Pontiac Fieros, Austin Rover MG EX-E, Jaguar XJ220 and Ferrari 408. Laser welding of stainless steel tubes was used, and engine and suspension subframes were bolted in the first prototyped model. GFRP and polyurethane (PU) were frequently used also.

As the results, weight was decreased by 27% and torsional stiffness was increased at 22%. Created production facilities didn't find any use in real industry, but project experience is used by Ferrari and Jaguar to estimate design efficiency. Following results were also achieved: heat treatment of aluminum 6xxx alloy was investigated; RRIM PU was proved for manufacture of vertical panels, front and rear ends; SMC was applied for hood and trunk. Flexible and recyclable material with fine dent resistance, RRIM PU, was profoundly researched as well as rigid SMC. Some of material estimations are presented in the tables 5 and 6.

In the times of ECV Audi was developing spaceframe concept program Audi Space Frame (ASF). Originally aluminum version of Audi 100 was obtained. Result of this toilsome work was a set of pressure castings, extrusions and sheet stampings. Welds, rivets and clinches were performed for assembly. Scrap portion decreased to 15%. Audi A8 aluminum bodies were developed based on the results of this program.

3.2 ULSAB

Ultra Light Steel Auto Body (ULSAB) is a program funded by 35 steel manufacturers from 18 countries, including JFE Steel Corporation (Japan), ThyssenKrupp Stahl AG (Germany), SSAB (Sweden), U.S. Steel Corporation (USA) and oriented to development of light steel automobile body. Project coordination was realized by International Iron and Steel Institute (IISI).

Car manufacturers have concerned about vehicle weight decrease again. After colossal ECV success there was a common opinion that effective solution is hybrid design of steel, aluminum and plastics. Steel manufacturers were interested to save market outlets, so collaboration arisen between automobile engineers and metallurgists of various companies. Consulting and training of employers, recommendations drawing up and counter offers caused to effective symbiosis and improving of steel position. ULSAB was initiated in 1998, when it was decided to compare and develop 9 most popular medium cars. Technical research was entrusted to Porsche Engineering Services.

ULSAB showed 90% HSS content in body and tailored weld bonding (TWB) in 50% joints. Hydroforming, sandwich panels and laser welding technologies were advanced also. Weight was decreased by 25%, torsional stiffness was increased by 80%, first body mode was increased by 58%, bending stiffness was increased by 52%, and parts number was decreased from 200 to 158 due to elaborated stamping. Moreover, manufacture cost remained permanent for volume production of 105 units a year. Set of automobile steel grades recommended by ULSAB for C class vehicle in the EU in 2004 is given in the fig. 5.

Table 5: Rating of materials by ECV

Material property	*Mild steel*	*Aluminum*	*HSS*	*PC*	*RRIM PU*	*SMC*
Weight/area for equal stiffness	1	0.5	1	0.7	1	0.6
Cost/area for equal stiffness	1	3	1.4	5	5	2.3
Weight for equal stiffness	1	1	1	15	20	4
Energy absorbed per unit weight at break in tension	1	1.4	1.2	3.5	2.3	0.02
Strength per unit weight	1	2	2.3	1	0.5	1
Corrosion resistance	-	+	-	+	+	+

Source: WorldAutoSteel

Table 6: Skin panel material selection by ECV

Material property	*Steel*	*Aluminum*	*RRIM PU*	*SMC*	*PC*
Useable thickness, mm	0.8	1.0	2.5	2.5	2.5
Damage resistance (elongation at yield), %	0.15	0.2	10	0.2	6
Weight/area	1	0.45	0.5	0.75	0.5
Cost/area	1	2.4	1.7	2.2	2.6
Corrosion resistance	-	+	+	+	+

Source: WorldAutoSteel

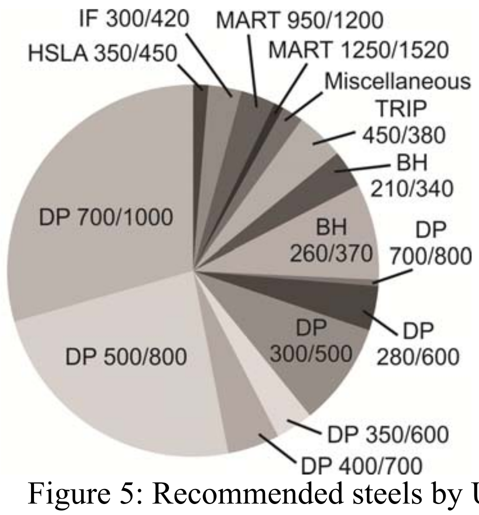

Figure 5: Recommended steels by ULSAB for C class vehicle in the EU (2004)
Source: WorldAutoSteel

Afterwards several subprograms were developed based on ULSAB: Ultra Light Steel Auto Closure (ULSAC) oriented to weight decrease of doors and hoods at 22% owing to reinforcement ribs development; Ultra Light Steel Auto Suspensions (ULSAS) oriented to suspension weight decrease at 34% via using of aluminum alloys; Ultra Light Steel Auto Body Advanced Vehicle Concepts (ULSAB-AVC) proposed to promote emergence of new steel grades and designs of cheap ($9000-10000) C class automobiles with fuel consumption 3.2-4.5 liters per 100 km, maximal recycling, safety and minimal emission (Titov, 2004).

3.3 FSV

Achievements of ECV and ULSAB inspired the UN climate change committee to declare FutureSteelVehicle program oriented to automobile emission decrease via modernization of high volume battery electric vehicles (BEV), plug-in electric vehicles (PEV) and full cell vehicles (FCV) and increase of battery and cells role in automobile energy supply.

FSV was founded after the Bali committee meeting in 2007. Program is oriented to development of safe and light AHSS body and promotes eco-friendly automobile power units. EDAG's Auburn Hills is a main executor of the program, and this company optimizes car designs, uses extended steel portfolio and latest manufacture technologies of automobile components. It is thought that set of automobile steels for 2015-2020 technological stage will be established in result of the program. FSV program has phases: 1) engineering research; 2) development of concept designs; 3) result presentation and comments. First phase included estimation of power units of high volume cars for 2015-2020 technological stage. AHSS bodies for BEV and PEV were designed during the second phase for A/B and C/D classes. FSV required weight decrease of all automobile parts and systems at 35% relative to analogues (Volkswagen models), not only body.

Main results of FSV: 1) Weight decrease at 35%; 2) 97% HSS body content; 3) 20 new AHSS grades were developed for 2015-2020 (ULSAB developed 11 new AHSS grades for 2002-2010); 4) Formable AHSS with ultimate stress more than 1 GPa occupy 50%: DP, CP, TRIP and TWIP; 5) 5 star EuroNCAP rating is achieved; 6) PEV emission is decreased by 70% relatively to car with ICE.

These steels were in use for development of BEV body: 1) HSLA 450, BH 340, 400 = 32.7%; 2) DP 500, 600 = 11.8%; 3) HF 1500 = 11.1%; 4) DP 1000 = 10%; 5) DP 800 = 9.5%; 6) TRIP 980 = 9.5%; 7) CP 100-1470 = 9.3%; 8) MILD = 2.6%; 9) TWIP 980 = 2.3%; 10) MS 1200 = 1.3 %.

3.4 FreedomCAR and PNGV

Desire to cheapen composites, foremost CFRP, and develop recycling technologies impelled US DOE and United States Council for Automotive Research, including Chrysler Group, Ford Motor Company and General Motors Company to subsidize Freedom Cooperative Automotive Research (FreedomCAR).

FreedomCAR was found in 2002 based on Partnership for a New Generation of Vehicles (PNGV) of 1993-2001. Program purposed to identify, establish priorities, coordinate and promote partnership between participants and other organizations (US

National Research Foundation, AISI, US Chemical Society, Canadian institutions) for research of advanced and competition automobiles. LightWeighting Materials is a subprogram focused on light materials and weight decrease of automobile bodies and chassis.

PNGV was a program-predecessor and dealt with manufacturing of GFRP and aluminum parts. These materials were recognized as the most suitable for weight decreasing at 40% and saving of manufacture cost. Important achievements of PNGV are casting and plastic stamping of aluminum parts. Then it was realized that aluminum and GFRP are not enough to complete assigned task, thus CFRP and magnesium alloys were introduced. Consequently, FreedomCAR appeared and goals were renovated: 1) decrease weight at 50% and save of manufacture and material cost; 2) develop manufacture and assembly technologies for CFRP and magnesium alloys; 3) cheapen CFRP. 4-doors sedans became main subjects of inquiry.

3.5 SuperLightCar

SuperLightCar is a program targeted to decrease fuel consumption and greenhouse gases emission, involving automobile companies Volkswagen, Fiat, Volvo, Daimler, Porsche, Opel, Renault and 33 suppliers, research institutes and universities. It is planned to decrease body weight of Volkswagen Polo Mk 5 by 39% (110 kg) in 2015, so expected weight is 171 kg. Body will consist in aluminum (53%), steel (36%), magnesium (7%) and plastics (4%). Casting and assembling are already developed and trial assembly is checking at factory.

4. Geographical aspects of automobile manufacture and transfer of factories

Region of automobile manufacture has a sufficient effect on material, technology and design choice. For example, steel electrogalvanizing is cheaper than hot-dip galvanizing in Germany, but vice versa in the UK. Here is a geographical breakdown of the average annual production of cars in 2007, mln units: Northern America – 8.5, Western Europe – 12, Eastern Europe – 4.3, Japan – 8.3, Asia Pacific – 21.5, Southern America – 3.4, other – 2. Materials of the EU and the US cars are shown in the tables 7 and 8.

Worldwide tendencies are revealed during 2003-2007 (Davies, 2003 and 2012): 1) share decrease of mild steel; 2) share increase of HSS for energy absorption improvement; 3) increase proportion of aluminum and magnesium in luxury cars; 4) growth of material variety in premium cars; 5) increase composites share in all market sectors, even for high volume models. Besides there is an adherence of Japan and China to low carbon steels due to orientation to volume export. Mass automobile production is generally conservative, moreover high automation and robotization are typical for Japan and often complicate introduction of new technologies.

Modern leaders of high-technological automobile industry (Western Europe, Northern America and Japan) adapt to law requirements and have sensitive response to changes in steel grades set. It results in general trend to apply HSLA, BH, DP, and TRIP. Traditional materials are common for nonbearing structures because cheapness is prior factor. CP and UHSS have some problems with welding, formability and product consistency, though wide progress is completed.

However novel materials emergence has restrictions from metallurgy. For example, Russian AutoVAZ has limited access to HSS steels (usual content is 78% of MS, 20% of HSS, 2% of UHSS) due to small variety of HSS products. Honda Jazz 2009 consists of medium strength steels (4% 780DP and 980DP, 42.3% HSS (590 MPa)) because the model is manufactured at most in China, Thailand and Brazil and HSS offer is poor there.

Table 7: BIW material grade analysis for a range of current European models

Vehicle	*Material, % per weight*						*Weight, kg*
	MS	*HSS*	*AHSS*	*UHSS*	*Al*	*Mg*	*BIW*
Volkswagen Polo	54	33	4	2	0	0	305
GM Astra	40.6	39.6	13.5	1.6	0	0	415.5
Ford C Max	48.5	28	15	10	0	0	463.5
Citroen C4	49.7	39.2	4.9	0	3.7	0	-
Alfa Romeo Guiletta	27.9	42	16.5	0	1.7	0	372
VW Sharan	23	64	2	1	0	0	489
Volvo S60	38	29.5	14.5	0.2	2.8	0.8	415.2
Honda Insight	48	49	0	3	0	0	361
BMW Series GT	16.3	35.3	16	1	14.2	0	490
Jaguar XJ	5	2	1	0	88	1	324
Audi Spyder	0	0	0	0	100	0	261

Source: Titov V. (2004) Steel rolling for automobile industry abroad

Table 8: BIW steel type analyses for the US models

Vehicle	*Type steel, % per weight*		
	MS	*HSS*	*AHSS*
GMC Arcadia	10	58	32
DCX M Class	45	15	40
Ford Expidition	45	25	30
Nissan Altima	45	18	37
Toyota Tundra	40	25	35
Honda CR-V	45	18	37

Source: Titov V. (2004) Steel rolling for automobile industry abroad

It is right to notice in favor of Russian industry that HSS content was increased in the latest generation of Lada Kalina (46% of zinced steel, 36% of conventional MILD, 18% of HSS). Moreover, reliance on foreign metallurgy was recently loosened due to industrial renovation of Magnitogorsk Metallurgical Integrated Plant in 2011 and expected expanding in Severstal metallurgical company. The government structures actively support steel import reducing and augmentation of automobile industry localization despite on requirements of World Trade Organization.

Nowadays lineaments of the US are economic health recovery of major automobile companies and efficiency increase of mass production and it results in using of well-checked, conservative designs and appearance of new materials. Among other things, stereotyped image about big size of American automobiles is still fair. And suspense of such dilemmas as “safety or fuel economy”, which have direct reflection on weight increase or decrease, allows keeping stereotype. Alike situation was in the Europe, when PSA Peugeot Citroen detected growth of average car weight by 10-15% caused by innovations purposed to decrease emission and increase safety: airbags, catalytic converters and energy absorption structures. Besides, optional audio systems and navigators were introduced. It alarmed PSA and decision was made to decrease weight and this solution reduced weight to average European value at 2005.

Despite such geographical aspects there are worldwide future trends of material selection: 1) Niche and performance cars: CFRP / light alloy / magnesium alloys; 2) Luxury and premium cars: hybrid AHSS / light alloy / polymer hybrids; 3) High volume cars: zinc-coated steels / AHSS / polymer hybrids; 4) Cheap cars (to 5000 euro): steel and minimal coated / HSS.

It is well known, that EU and the USA undergone recession in 2008-2010, thus vehicle production volume was constant there, but rise occurred in China and Eastern Europe. It could be explained by cheaper labor force, and hence, investment attractiveness. However factories transfer may cause harmful influence on brands reputation such as BMW and Daimler. Despite this fact many automobile parts and structures of these companies are manufactured in China and India, and prestige Porsche Cayenne is assembling in Slovakia.

Cheapness of labor force and relative nearness provokes western manufacturers to settle plants in Eastern Europe (in Bosnia, Hungary, Poland, Czech Republic). Volkswagen assembly Audi, SEAT and 3 Volkswagen models in Slovakia. Opel is going to open factories in Hungary and Poland. High volume production (7·105 units per year) of Renault Logan was started in Romania in 2004 and oriented to markets of Morocco, Columbia, Russia and Iran. Skoda is planning cheap cars production in Bratislava. Ford and FIAT will manufacture cheap cars for European customers in Poland.

Besides investments simultaneously come from various companies, so creation of unitary base for several models is typical and it reduces production cost, simplifies standardization and maintenance. Joint production (more 105 units per year) of Toyota and PSA in Czech Republic is a good example.

Transfer of factories always presents adaption necessity of conventional manufacture technology to supply channels and regional technological level. Proper contact with local metallurgical companies is essential and safety and ecological local standards must be met, price question is important also. In view of these circumstances one model, which manufactured in various regions, differs both in material content and technical performance. Example is Toyota Aygo and small class cars PSA in Czech Republic. Western car manufacturers invest in China and Russia too. But steel variety is poorer there, so capability checks of metallurgical industry is required.

At present days transfer of Japanese factories to the Europe is going on. Japanese brand cars could be a source of serious technological competition and Japanese companies are able to occupy share of market. It is not a secret that progress in European steel manufacture was inspired by Japanese influence in 1990s. Continuous cast and anneal were successfully developed by Japan, despite in 1950s the UK was a pioneer in this field.

5. Cost, safety, repair and maintenance

Reader may get inspired after previous paragraphs by technical performance of light materials and body designs. However, important aspects, which have a great effect on emergence of light materials in high volume automobile structures, are covered in this chapter.

5.1 Cost

Introduction cost of new materials is a prior factor for high volume production. Interesting comparison of total investment cost for steel, aluminum and polymer body production is shown in the fig. 6. Low volumes are sensitive to investment cost, high volumes – to material cost. Expensive investment, cheap material and high production rate is typical for steel bodies. Cheap investment, expensive material and low production rate is normal for plastic castings. Aluminum cost is high and investment cost corresponds to zinc coated steel. Finally, polymer bodies are more profitable for low volumes, and steel bodies are efficient for high volumes. Break point dividing polymers and steels, lies at volume of 2·105 units per year. Volume is deemed medium if it does not exceed 2.5·105 units per year. Thus aluminum and plastic are typical for low volumes only.

Opportunity to decrease cost depends on technology development: 1) decrease tools cost and scrap production (down to 25%) for steel bodies; 2) cheapen aluminum, for example, by development of continuous casting technology; 3) decrease weight of steel bodies by 40%; 4) decrease polymer costs by using of CFRP.

Dieffenbach completed fascinating cost estimation analysis of medium size sedan in the EU (1997, 1999). Comparison of steel, aluminum and composite frames, unitary body and spaceframes (tables 9, 10) showed than aluminum spaceframe has 15% cost penalty compared to steel unitary body and thus aluminum can compete with other materials. Stainless steel spaceframe is an interesting solution reducing cost of painting. It is obvious that appearance of fully stainless body as Delorian DMC-12 is excluded (Schuberth et al, 2008).

5.2 Safety

Safety issue for automobile transport is a complex problem. It comprises safety of driver, vehicle and road infrastructure and could be solved considering all these cases only. Recently probability growth of road traffic death was detected in many regions. Despite on significant efforts a great amount of people annually dies in accidents, for example, 9·104 in the EU, 4·104 in the USA, 2.7·104 in Russia and 2.8·105 in China. The probability reaches 5·10-5 year-1 in the safest European countries and 1.5-2·10-4 year-1 in other countries of the region. Higher probabilities are typical for BRIC countries: 1.8·10-4 year-1 in Russia, 1.9·10-4 year-1 in India, 2.05·10-4 year-1 in India. It is stated in the World Health Organization report that only 7% of world population live in safety from transport. Thus safety issues attract more and more attention (Psarianos, 2005).

When automobile safety question comes, passive safety and energy absorption are usually meant. These characteristics are estimated by EuroNCAP. This organization grew from the UK Transport Research Laboratory and developed tests for active and passive safety. 5 stars EuroNCAP is a hot desire of car companies (Morello et al, 2013). Comparison of modern EuroNCAP ratings and 10-15 years ago shows vast progress, particularly in body design. Though efficiency degree of safety precautions at road infrastructure and transport design demonstrates delay in the second case in the EU (Winkelbauer and Machata, 2007).

Energy absorption is a key design parameter for longitudinal and side intrusion beams. The parameter depends on design geometry, material strength and plasticity. DP, CP and TRIP have an advantage among other HSS due to outstanding combination of plasticity and work hardening. However, aluminum alloys have even better energy absorption: simple single profile panel made of common aluminum have analogue energy absorption that heavy complex profile steel panel has (fig. 7). Certainly sandwich panels and cell structures have very good position also, but their production is more complicated. Pedestrian safety is a hotly debated issue in scientific and technical community also. As typical result, Jaguar XJ 2009 and GM Astra 2009 have destructible inner hood panels, which allowed raising EuroNCAP ratings.

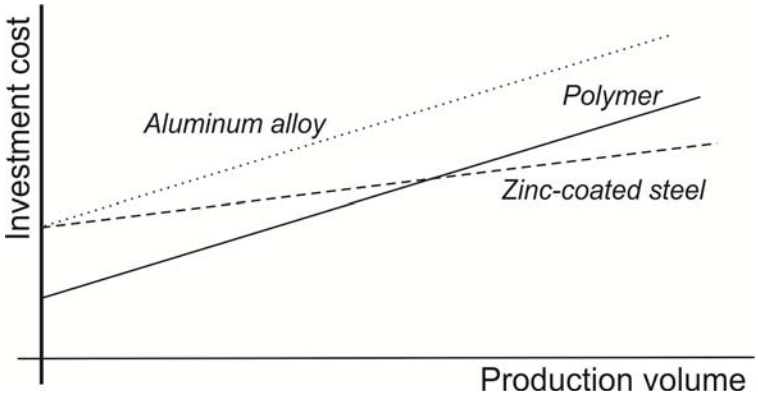

Figure 6: General cost basis for automobile body materials

Source: Dieffenbach J.R. (1997) Challenging Today's Stamped Steel Unibody: Assessing Prospects for Steel, Aluminum and Polymer Composites

Table 9: Key design inputs for design and materials

Characteristics parameters	*Steel unibody*	*Aluminum unibody*	*Steel spaceframe*	*Aluminum spaceframe*	*Composite monocoque*
Geometry characteristics					
Overall vehicle mass, kg	315	188	302	188	235
Mass as (%) of steel unibody	100	60	96	60	75
Spot joints, items	3250	3400	-	1000	-
Seam joints, cm	-	-	4000	-	6000
Total piece count, items	204	224	137	137	41
Material characteristics					
Total piece count, $/kg	0.77-0.92	3.00-3.50	0.77-2.20	2.00-3.00	3.13
Density, kg/m3	7850	2700	7850	2700	1590
Material cost, $	243-290	564-658	233-664	564	736

Source: Dieffenbach J.R. (1997) Challenging Today's Stamped Steel Unibody: Assessing Prospects for Steel, Aluminum and Polymer Composites

Table 10 – Relative costs of steel unibody and stainless steel spaceframe ($)

Item	*Steel unibody*	*Stainless steel spaceframe*
Structure	748	522
Panels	198	191
Assembly	261	115
Paint	451	314
Total	1615	1142

Source: Dieffenbach J.R. (1999) Not the Delorean Revisited: An Assessment of the Stainless Steel BIW

5.3 Repair

Undoubtedly, parts made of conventional steels are easy to repair and regain original shape. There are complex parts in modern designs using for local structure optimization, for example, in front and rear safety zones, side impact zone and for external panels. Arbitrary heating or straining of body components, which were not considered by designers, can negatively effect on reliability of reshaped part. Profound knowledge of maintained structure is required to prevent detrimental consequences. Thus repair technology must follow the specification (Robinson and Livesey, 2013).

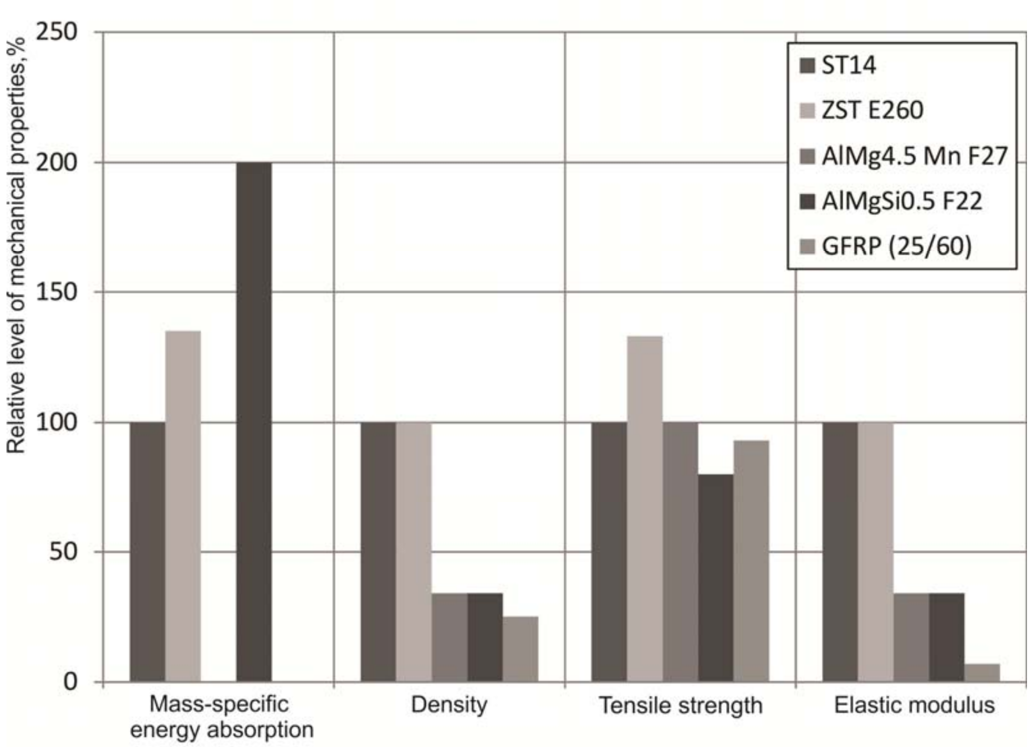

Figure 7: Mass-specific energy absorption, density, tensile strength and elastic modulus of automobile steels, aluminum alloys and GFRP

Source: Ostermann H. et al. (1993) Aluminum Materials Technology for Automobile Construction

PAS 125 specification of British Standard Institute is valid in the UK at the present time and it specifies body repair procedure. According to the document, repair services must demonstrate working process and equipment availability for maintenance of "exotic materials" to get accreditation. It promotes these organization recruit specialists. However this practice obstructs using of novel materials such as AHSS. Alike law is valid in the USA also. Hence many efforts are applied to rectify HSS in order to repair possibility, and received data are used in authorized repair centers. This problem aligned with aluminum alloys also.

Conversely, CFRP have another problem. CFRP fragment distribution after impact and remained debris on the road are serious hazard for road users. Repair and regain original shape is very labor-consuming. If part admitted to be unrecoverable, then insurance rate grows and it repels customers. Besides, many plastic parts have no recycling technology, and refuse to repair means inevitable environmental pollution (Davies, 2012).

5.4 Recycling and disposal

Disposal is one of the stages of Life-Cycle Analysis (LCA) approach. This concept emerged in 1990s in response of industrial corporations to enforcing of environmental laws. Modern automobile must be eco-friendly not only in exploitation, but in manufacture and disposal too, another words during all life cycle. There is a LCA application problem, because manufacture methods are various and their analysis is complicated, thus LCA requires methods uniformity as it is lobbied by Society of Environmental Toxicology and Chemistry and International Organization for Standardization.

Problems of steel, aluminum bodies and automobile emission are supervised by IISI. IISI requires following: 1) National ecological laws must specify energy expenses and pollution in manufacturing and disposal also because it is crucial for some light weight materials; 2) Customer must be informed not only about decreased body weight and improved fuel economy, but about complicated repair and high insurance rates too. Such restriction decreases aluminum consumption in automobile industry (Belyaev et al, 1983). Main demand to plastics is variety decreasing (rationalization) to simplify disposal. It is recommended to short automobile plastics variety from 200 to 20 types, and to apply 6 types (PP, PU, ABS, PE, PVC, and PA) in 70% of cases.

End-of-life Vehicle program was launched according to Directive 2000/53/EC in 2000. This document states that vehicle recycling degree is specified to be not less that at 75% (2003), 85% (2006) and 95% (2015) for sale in the EU. Though according to AISI report steel body may be recycled by 94.5% in 2013, and the Directive spawns second thoughts about achievability of 95% recycling level considering that modern bodies contents not only well-recycling steel, but huge variety of materials (Carrabba et al, 2013).

6. Conclusions

Strong competition of automobile material market is an essential matter, which conditioned by market size and cost. Earlier environmental concerns dictated fuel consumption reducing and recycling technology development, and this brought composites and light materials to the market. However there are still barriers in materials use, primarily of economical nature. Research of manufacture technology, material properties and cheapening methods is a question of present interest. Steel manufacturers promote structure development programs and in such a manner they exhibit ability to continue struggle for steel supremacy in material market. At the same time scientists also develop novel materials such as alternative metals and composites and find original solutions for light and eco-friendly vehicles. Undoubtedly, these materials cannot fully displace steel in short-term period, but some steel parts might be replaced even today (table 11).

Finally, main conclusions are shown below:

1) Radical changes in design or material selection will not occur due to conservatism of high volume industry. In short-term period development of steels and aluminum alloys is expected to decrease vehicle weight. Aluminum share in high volume automobile bodies most probably is going to rise. Main efforts of scientists and engineers are oriented to properties development of existing materials, improvement manufacture technologies, but not appearance of new materials. In medium-term period

hybrid of metal materials (steel, aluminum and magnesium alloys) for safety structures and plastics for roof members, hood and external panels seems to be efficient. Long-term period is attributed by emergence of efficient alternate vehicle power units and corresponding adaptation of low steel design.

2) Body weight decrease more than by 30% means light material application and necessity of large changes in manufacture and recycling.

3) Sheet steel is more suitable for high volume and HSS and coated steel are for medium volume production.

4) Aluminum alloys appear very promising among other alternative materials for particular steel displacing for mass production. Though, price cost and stability for aluminum sheet still leave much to be desired.

5) Composites usage is expanding, but material price and recycling issues are still excessively critical for volume production. Besides, appearance of efficient plastics recycling technology will not cause their popularization if safety issues and part scale problem will be unsolved.

6) Composites, light cell structures and sandwich panels appear to be main future automobile body materials with alternative power units.

7) Hybrid material body emergence is inevitable. For example, steel and aluminum hybrid with polymer external panels can ensure simple material identification, repair and recycling.

8) It is necessary to consider environmental “friendship” and manufacture simplicity (chain process concept), but not only physical and chemical properties of material during material selection routine.

9) Electromobility concept effects on design. Modern typical feature is adaptation of heavy hybrid and electric power units to regular design and supplementary damage protection.

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