AL−ALLOYS SHEET METALS − ADVANCED MATERIALS FOR APPLICATION IN CAR BODIES

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ABSTRACT

During the last decades car industry has been going through an intensive development which integrates the latest achievements in science and technology. Development and usage of new materials for car industry, especially for car bodies, has been coordinated with general social demands, saving of economic resources, energy preservation and ecology, passengers safety etc. According to that, during the last few years materials for making car bodies of reduced weight have been more and more used, such as: high strength steel sheets, Al−sheet metals, titan and its alloys, taylored sheets, sandwich and composite materials and similar. Usage of Al−alloys makes possible the weight reduction, satisfying at the same time the demands for car body stiffnes, which reduces the consumption of fuel and makes space for additional building−in of active safety elements. However, due to reduced formability in relation to low carbon steel sheets metals, replacement and introduction of Al−alloys demands great technological coordination in the existing productive process, i.e. realization of completely new elements of the forming system. The aspect of choice of new materials are given in details in this paper, with particular retrospection to formability of classic and Al−alloys sheet metals by deep drawing.

1. INTRODUCTION

Reduction of fuel consumption and of exhaust gases emission represents one of the most important developmental tasks for car producers all over the world. By integration of the latest achievements in science and technics, the distinguished results in this field were realized regarding the engine construction and manufacture of light car bodies. Development and usage of new materials in car industry, especially for car bodies, has been adjusted to general social demands, economic resources saving, energy preservation and ecology, passengers safety etc. With this purpose, during the last few years materials of reduced weight are more and more used for car bodies making; such materials are: sheet metals of high strength steel, Al-sheet metals, titan and its alloys, sandwich and composite materials etc /1/. The usage of Al-alloys enables the reduction of weight and it also satisfies the demands for car body stiffness, which reduces the consumption of fuel and makes space for additional installment of active safety elements. However, due to reduced formability in comparison to low-carbon steel sheet metals, the replacement and introduction of Al-alloys demands a variety of technological adjustments in the existing production process, that is the realization of completely new elements of forming system.

Out of the total car mass 32% in average goes to the car body, fig.1 /2/. It is obvious that the reduction of car body mass significantly contributes to the reduction of the total car mass. In general, the reduction of the car body mass can be realized by the change of concept of the car body structure and by replacing classic materials with lighter ones. The choice of car body materials is performed on the basis of several criteria, which are given in table 1.

In car industry steel for deep drawing and appropriate techniques of fast and reliable joining of car body parts has been developed for years. The introduction of aluminum has imposed comprehensive researches with the aim to find the alloys and states of alloys, which would provide the most convenient combination of ability of shaping and hardness at sheet metals. The other important group of investigations was carried out in order to find the most convenient procedures of jointing and of course the provision of high resistance to corrosion - especially stress corrosion. This paper gives a short survey of alloys that are used in car industry today and its possible application in domestic car industry. Here we should also mention that there is a special area which consists of cast or pressed profiles of Al-alloys which are also introduced into the constructions of transport vehicles, which will not be considered in this paper.

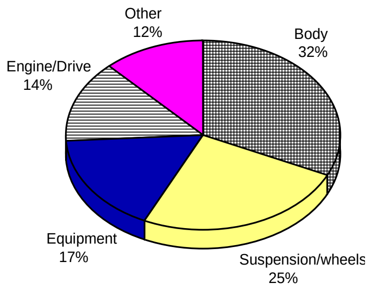


Fig. 1 Vehicle weight composition ratio

The first attempts to introduce Al-alloys into the construction of passengers cars date back to the twenties of this century (Rolls-Roys and Pomeroy) /3/. Periods of various interests of car industry in usage of aluminum have passed since then. Today, in the period of strict demands regarding the environment preservation and saving of all kinds of energy, this interest is favored more than ever.

Cost
Quality and it's stability
Stable supply
Functional characteristics: **−lightening effect** **−strength** **−corrosion resistance**
Productivity in mass production: **−formability, machinability** **−weldability, jointability** **−no change of classical production system**
Disposal and recycling

Tab. 1 Standard of selection of sheet materials for autobody

In the history of Al-alloys application for manufacture of car bodies or their parts, for most car producers both in Europe and in America, in the initial stage of development, alloys 2036-T4 based on copper and 5182-O based on magnesium play the dominant part /3, 4/ (chemical contents are given in Table 2). By the application of these alloys the requested car body stiffness was achieved by assembling of sheet metals with increased thickness in comparison to steel in range 20% to 40%. The alloy 2036, which is previous to aging (it strengthens by aging) was used for the manufacture of outer car body parts, while the alloy 5182−O, due to its characteristic relief owing to Luders' strain, directed more to the manufacture of inside car body elements. In comparison to the alloy 2036, the alloy 5182 strengthens by cold strain and by the effect of dissolving strengthening of the magnesium. Out of this difference one important difference in the behavior during baking of painted car body appeared. Actually, on increased temperature, on which the baking of the paint is carried out (around 200 ^{o}C), the hardness of AlMg alloy decreases and at 2036, due to sedimentary strengthening significantly bigger hardness can be provided. The combination of these alloys is, however, very inconvenient from the aspect of the secondary treatment in the means of waste due to copper present in the alloy 2036. In searching for the alloy that would be compatible in waste with the series 5000, alloys from the family 6000 on the basis of AlMgSi were chosen. Also, the alloys from these series do not have the Luders' strain, they have high hardness after aging and are very convenient for welding. Their main disadvantages are small ductility (the ability of shaping) and appearance of specific surface with ”ridges” parallel to the direction of rolling due to specific texture. Chemical contents of the alloys 6000, which are used in car industry, are given in Table 2. Mechanical properties of aforementioned alloys are given in Table 3. The forming limit curves both for the investigated Al-alloys and for car body steel are given in the summary in fig. 2. The new alloy of the type 6016 which has in its content the biggest quantity of Si achieves the level of shaping ability of the alloy 5182-O and it is often mentioned as Anticorrodal Al-120T4.

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
2036	0.40	0.29	2.5	0.30	0.40	0.01	0.04	0.05
5182	0.12	0.25	−	0.40	4.5	0.01	−	0.02
6009	0.8	0.50	0.33	0.33	0.50	−	−	0.02
6010	1.0	0.50	0.33	0.33	0.80	−	−	0.02
Ac−120	1.25	0.25	0.07	0.07	0.40	0.025	0.016	0.02

Tab. 2 Chemical composition of typical Al−alloys intended for autobody (%)

	2036T4	5182−O	6009T4	6010T4	Ac−120T4
R_P, MPa	185	130	131	186	127
R_M, MPa	320	252	234	296	235
φ_M, %	20.0	22.0	19.0	20.0	24.6
φ_u, %	24.0	25.4	24.0	23.0	28.1
n	0.21	0.34	0.23	0.22	0.26

Tab. 3 Mechanical properties of alloys from Tab. 2

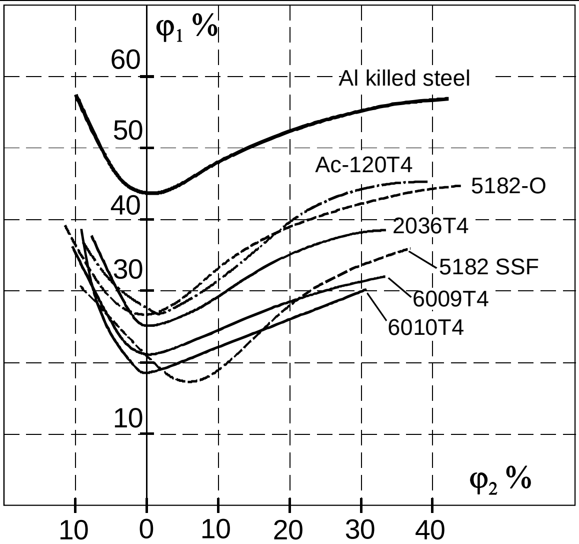
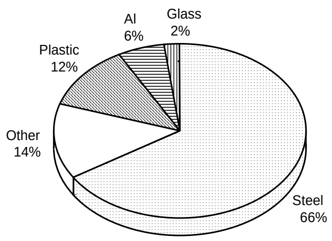


Fig. 2 Forming limit curves of Al−alloys for car industry

The more significant application of aluminum for manufacture of some car body parts started by use of Al-Mg-Zn alloys in the eighties (engine cover, door, mudguards and similar – parts which are "hanged" onto the car body). On the world market now there are cars whose complete car body is made of Al-alloys (Audi A8, Audi A2, Mazda AZZ550, Porsche EXP). The general prognosis for Al-alloy application on cars with cars with classic car body is shown in fig. 3 and fig. 4 /2/. The comparisons are given for the European cars for 1998 and for situation 10 years later. The total percentage of AL-alloys usage increases from 6 to 12%, that is from 70 to 120 kg in total or from 5 to 30 kg per car body. The Japanese prognoses are different and according to them the Al-alloys usage will be up to 15% on cars of medium and lower class, and up to 25% on high performances cars.



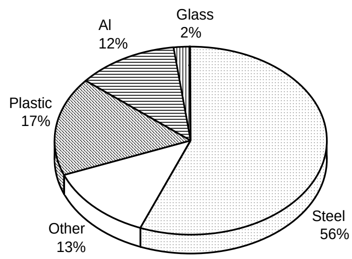


Fig. 3 Using of Al on vehicles (all materials), left−year of 1998, right−2008 (prediction)

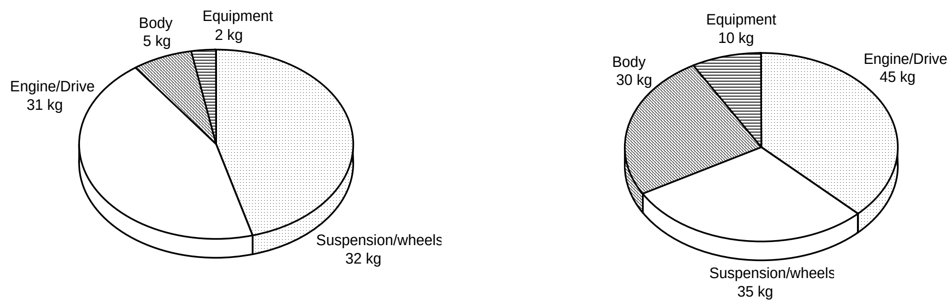


Fig. 4 Using of Al on vehicles (only Al alloys) , left−now, right−after 10 years (prediction)

2. APPLICATION OF Al-ALLOYS IN THE NEW APPROACH TO THE CAR BODY CONSTRUCTION

The usage of new materials in car industry is highly dependent on the type of car the material is installed in. Usually, cars are in general divided into small, medium, high class and special cars. According to the analyses of Hoogovens (Benelux), the research and development center of world famous producers of various materials for car industry, the following usage of materials per type of cars are anticipated /5/:

- For the lower class cars no significant changes regarding the usage of existing materials are expected. Mainly steel will be used.
- For high-class cars, there will be some changes in the used material regarding some parts. On the model Audi A8 the entire car body is made of Al. However, such concept is not expected to be accepted by the other producers. The following generation of these class cars will most probably have the car body made of high strength steels (HSS) with intensive use of so called previously tailored blanks. The parts which are "hanged", such as doors, mudguards, engine cover and similar, will be made out of lighter materials such as Al or plastic
- Changes in high class will also significantly influence the medium class cars. The project of cars with ultra light car body (ULSAB) in which over 30 world car producers can serve as an illustration of those changes. The aim of this project, which directed the development from the Porche, was to make the car body of medium class cars which will be 20% lighter than the existing one, at the same price and with the same properties of stiffness and resistance to stroke. With that purpose the following materials were used: high strength steel, tailored blanks, parts obtained by hydro shaping, sandwich materials and plastic.
- Sport cars and electro-cars will have the entire car body made of Al with parts of steel, plastic, Al, magnesium and sandwich materials.

During the last few decades the conventional car structures are constantly getting harder. The reasons for this are higher demands for better safety: (air bags, anti-block systems on brakes, strengthening on the side and similar), for better comfort (air-conditioning, more forceful brakes, more precise steering and similar), for better performances etc. The adjustment of the engine power to these demands requires stronger chassis and increase of mass. Long-distance driving requires the increase of the size of reservoir. Aforementioned demands are followed by increase of car body stiffness. In this way the spiral of car mass increase is created, fig 5 /6/.

Researches in line with the previous observations led the car producers into developing the new approach to the car body construction, whereas its basis is made exclusively out of aluminum. In this way the car mass is significantly reduced which is the first step towards the turning of the mass increase spiral in the opposite direction, fig. 6 /6/. Within the next step the

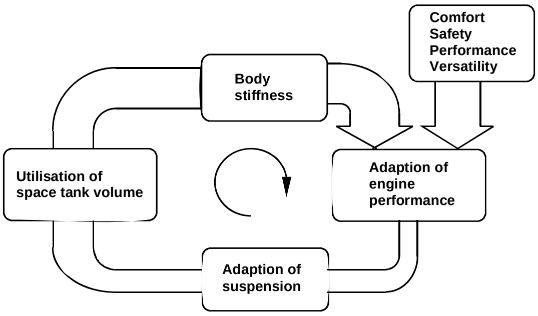


Fig. 5 Weight spiral

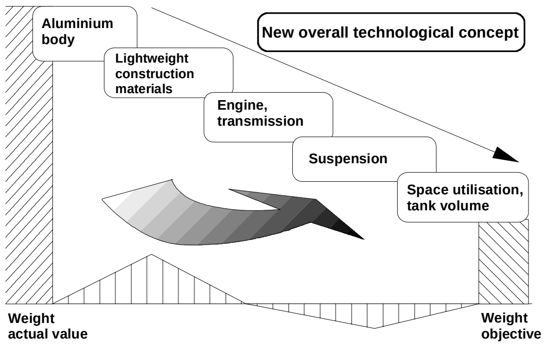


Fig. 6 Reversal of the weight spiral

other parts can also be reconstructed and lighter materials can be used. These first two steps lead to additional costs. By keeping the car performances constant, it would be possible to use smaller engine and gear. For lighter car body and engine of smaller power the lighter chassis, smaller reservoir etc must be used as well. The last three steps in such a procedure reduce the car exploitation costs.

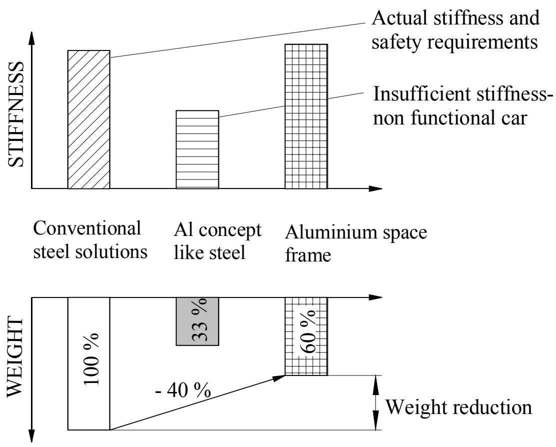


Fig. 7 Weight and stiffness for aluminium and steel

In the beginning of Al-alloys usage for these purposes, the simple replacement of steel sheets with aluminum sheets, at equal thickness, was applied. In this way the reduction of weight for 66% was realized but also the reduced stiffness and certain functional disadvantages, fig. 7 /6/. Local strengthening can solve some of these problems, but the concept basically corresponds to one with use of steel sheets. The solution is a new concept according to which the entire car body is made of aluminum. In such a concept Al-alloys sheet metals and Al parts obtained by extracting and casting are used. The investigations showed that if the local strengthening by square section profile of steel is replaced by the same one of aluminum, the mass reduction for 50% is achieved with no changes regarding functioning.

3. THE PROPERTIES OF AL-ALLOYS SHEET METALS

The main properties of Al-alloys are:

- Yield strength and tensile strength are lower in comparison to steel
- Elasticity module has three times smaller value in comparison to steel
- Elongation, especially local, is small
- Normal anisotropy coefficient is small (below 1)
- Relatively small hardness with surface which is easily damaged

It is obvious that Al-alloys have reduced formability in comparison to steel. During investigations of formability of these materials, methodology developed in case of steel sheet metals usage (mechanical properties, tests of pure deep drawing, stretching, limit forming diagrams, deflection tests etc) can be used completely. Tribological conditions are extremely important in Al-alloys forming by deep drawing, firstly due to small hardness and intensive compacting of Al to steel. For defining of optimal contact conditions, especially of type and zone of lubricant application, well-known tribo tests are used: bend sliding between flat contact surfaces, over draw bead, as well as more complex models (deep drawing, stretching).

4. THE RESULTS OF EXPERIMENTAL AND PRODUCTION INVESTIGATIONS

In programs of passenger cars ”Zastava” aluminum has not so far been used for manufacture of car bodies parts. By cooperation of Rolling mill from Sevojno, the Institute for cars ”Zastava” from Kragujevac, Faculty for Technology and Metallurgy from Belgrade and the faculty of Mechanical Engineering from Kragujevac the realization of the program of conquering the parts of external car body cover of Al-alloys. On the basis of comprehensive analysis of experience of other car producers so far and of our possibilities, potential parts for production have been selected, materials have been chosen and conditions for production of special kind of sheet metals have been made in Sevojno. It has been planned to produce parts which are independent on car body basis: mudguards, hood, doors and similar.

For initial conquering left mudguard of the vehicle YUGO was selected, which is made out of steel sheet metal C0148P5− 0,8 mm thick. This part was chosen because it can be attached without welding and is of relatively simple geometry.

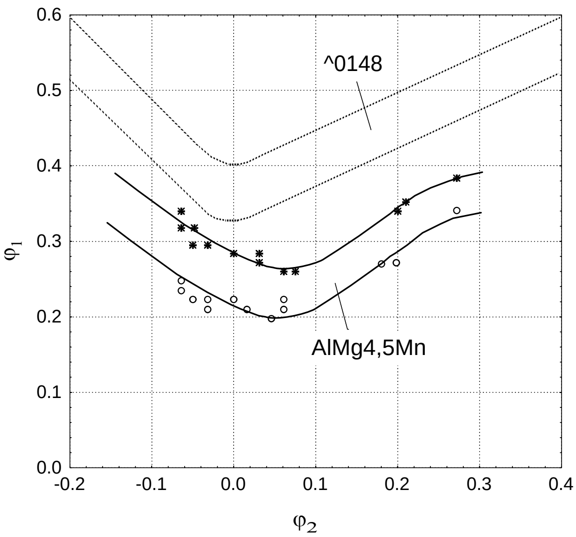


Fig. 8 Forming limit diagram for Aluminium and Steel

Test examinations were performed with sheet metal of alloy AlMg4,5Mn, of thickness 0,8mm and 0,9 mm. The properties of this material were investigated in details in other papers of authors from stated research institutions. The basic forming limit diagram for steel and aluminum sheet metal is shown in fig. 8. The difference in ability for shaping, especially in the area of plane stress state (the zone of bending around small radii) is obvious /8/.

Forming by deep drawing has been carries out in operating conditions, on the line on which the specified part was produced out of steel sheet metal. In the first tests, at unchanged working conditions, fracture appeared in the zones of draw beads. After successive adjustments of the holding force and height of draw beads, change of lubrication location with use of lubricants of high viscosity and polyethylene foils and new balancing of the holder, a pressed part was successfully obtained, fig. 9. In the later stages of bending, cutting and similar, at the locations where bending was sharp local cracks occurred which do not endanger the functionality of the part.

For more thorough analysis of limit formability, a methodology of measuring grids was used. Before deep drawing, measuring grid, which consisted of circles of 3 mm diameter, was applied electrochemically onto the surface of the blank in the zones which can be critical regarding the value of the biggest strains. After shaping dimensions of grid ellipses are measured and values of main line strains are determined. For such parts the zones on the angles in the fields of the largest tangential stresses are specific. The distribution of the third main strain, that is the thinning strain on sheet metal thickness for the section on right upper angle of the pressed part is given in fig. 10. The larger values of thinning for Al-alloys are obvious.

The particular problem at such replacement of the material is the new thickness of the material. Actually, already at thickness of 0,9mm, in following forming operations, after deep drawing, demolition of clearance and forceful sheet metal thinning occur. Real replacement with the material of thickness 1-1,2 mm in the present technological conditions is not possible. In further investigations the problems of technological coordination, assembling, surface protection etc, will be considered in more details.

Fig. 9 Left YUGO's fender panel

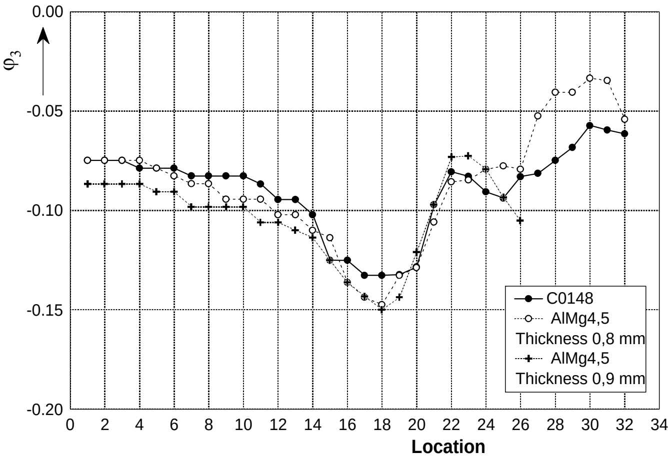


Fig. 10 Strain distribution of sheet metal thickness

5. CONCLUSION

On the basis of performed examinations, laboratory and production investigations, we can conclude the following:

- In forming conditions which refer to deep drawing of steel sheet metals, parts of Al-alloys cannot be successfully obtained,
- The working area of the holding force should be narrowed considering the appearance of wrinkles, that is fractures,
- Geometry of draw beads must be changed,
- It is necessary to change the scheme of lubrication along with the use of high viscosity lubricants at certain locations,
- Considering the sensitivity of Al-alloys sheet metals surfaces it is necessary to pay a lot of attention to their storing and manipulation (maybe applying of protective foils over sheet metal should be included).

Generally speaking, the difficulties at deep drawing of Al-alloys sheet metals can be grouped in the following way /9/:

1. The elements of forming cannot clearly be controlled which makes difficult the proper choice of materials for certain pressed parts,
2. Working area of the holding force is narrowed in comparison to steel,
3. The shape fixability is made worse due to the small value of the elasticity module,
4. Classic mode of manipulation is more difficult due to non-magnetism of Al-alloys.

The solution to these problems can be realized by the development of: new alloys with higher formability, methods for determining of formability, forming technology and lubrication technique.

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LIMOVI OD Al LEGURA − SAVREMENI MATERIJALI ZA PRIMENU NA KAROSERIJE AUTOMOBILA

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REZIME

Aluminijumske legure zbog svojih izrazitih prednosti (manja masa, koroziona otpornost itd.) zamenjuju čelične limove na karoserijama automobila u sve većem procentu.

U ovom radu, pored pregleda stanja i trendova u oblasti primene Al limova u svetu, dati su neki od rezultata pionirskog pokušaja primene lima od legure AlMg4,5Mn domaće proizvodnje na pojedine otpreske karoserije vozila Zastava YUGO. Osnova intencija u istraživačkom pristupu bila je da se sagledaju mogućnosti primene ovakvog novog materijala u postupcima oblikovanja pri postojećim uslovima (mašine, alati, procesi) koji važe za čelični karoserijski lim i ustanoviti kakve promene treba izvesti.

Na osnovu izvršenih istraživanja, sagledavanja, laboratorijskih i proizvodnih ispitivanja, može se zaključiti sledeće:

− u obradnim uslovima podešenim za čelični lim, prostom zamenom materijala (Al lim umesto čeličnog) nije moguće dobiti uspešan deo,

− potrebno je suziti radno područje sile držanja s obzirom na pojavu nabora, odnosno razaranja,

− potrebno je promeniti geometriju zateznih rebara,

− nephodno je uvesti novu šemu podmazivanja i nova maziva (visoke viskoznosti),

− zbog meke i osetljive površine i nemagnetičnosti limova od Al legura treba posvetiti posebnu pažnju skladištenju i manipulaciji ,

− sposobnost zadržavanja oblika je pogoršana zbog male vrednosti modula elastičnosti.

Rešavanje ovih problema može se ostvariti razvojem: novih legura sa većom obradivošću, metoda određivanja obradivosti, tehnologije oblikovanja i tehnike podmazivanja.