DEVELOPMENT AND APPLICATION OF AL-ALLOYS IN MANUFACTURE OF CARBODY ELEMENTS

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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. In order to reduce the vehicle weight, i.e. exploit the vehicle more economically, the consumption of light materials in fabrication of passenger cars grown during the last few years. The application of Al-alloys sheet metals, first of all in manufacture of car body elements, is extremely important. Because of reduced formability of Al-alloys sheet metals in comparison to steel sheet metals, many difficulties may occur while using these materials. Decrease of strength, intensive strain localization and sensitivity to tribo-conditions are main limiting factors in application of Al-alloys. This paper gives the characteristics of different Al-alloys with application areas, standard and special formability parameters, and results of laboratory and production investigations when using carbody elements.

KEYWORDS: Al-alloys, sheet metal, deep drawing, formability

1. INTRODUCTION

The development of the passenger car body structure, in the sense of design, is at the optimal level, especially for the models that are coming out to the market for the first time. In order to enable compliance to ever-stricter safety regulations, reduction in vehicle weight, etc., the application of new materials, that is new technologies, is required. The development and usage of the new materials for automobile car body is in accordance with the general requirements of a society (saving of the economical resources, preservation of the energy sources and environment, passenger safety improvement etc.). Therefore, the materials used for car body manufacturing have been significantly of less weight in the recent years, such as: high strength steel sheet metal, aluminum sheet metal, titan and its alloys, sandwich materials and the like. Reduction in weight, together with compliance to the car body stiffness requirements, causes the fuel consumption reduction and creates the room for additional installment of the elements for active and passive safety improvement. However, a simple replacement and introduction of new materials require a number of the new technological solutions in the existing production process, that is the creation of the completely new processing systems. Summary survey of the car production development in the function of social changes and development of technology in Japan in the last four decades, is illustrated in fig. 1 /1/.

From the formability standpoint, there are numerous problems in manufacturing body parts using light materials. In general, formability of light materials is lower compared to low-carbon steels. In this case, in addition to material destruction, there are also problems in the form of wrinkles, surface deflections and springback. The dominant characteristics related to outer

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pressed parts are stiffness, shape fixability and surface quality, while the important features of the inner components are the stiffness of certain pressed parts and the complete structure, as well as the fatigue strength /2/.

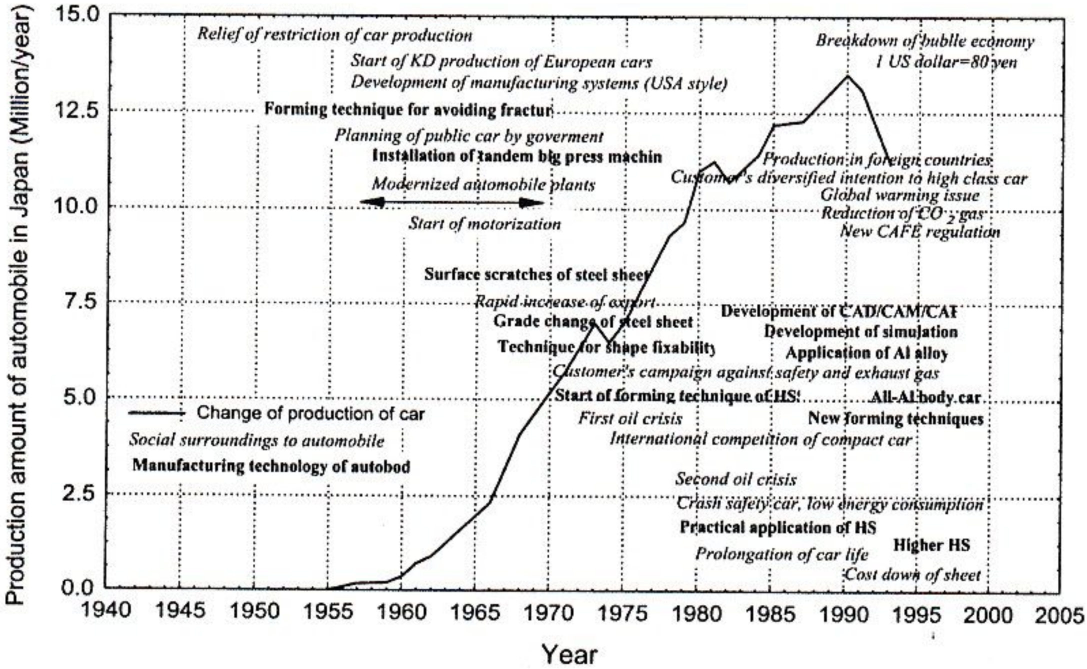

Figure1: Change of car production in Japan , social surroundings related to automobile and manufacturing technology of autobody parts /1/

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

Out of the total car mass 32% in average goes to the car body. 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: cost, quality and it's stability, stable supply, functional characteristics (lightening effect, strength, corrosion resistance), productivity in mass production (formability, weldability, jointability, no change of clasiccal production system), disposal and recycling.

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.

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. 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 /4/:

- 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 and A2 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.

3. THE PROPERTIES OF AL-ALLOYS SHEET METALS

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. 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. 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 /3/.

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).

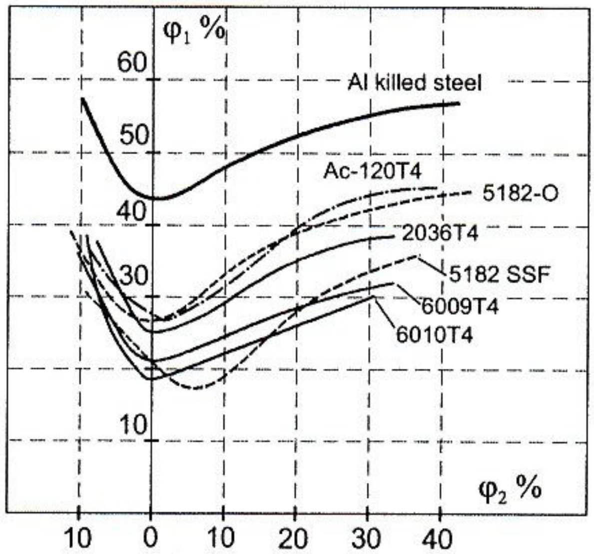

Figure 2: Forming limit curves of Al–alloys for car industry /3/

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 /5/. It has been planned to produce parts which are independent on car body basis: fenders, hood, doors and similar.

For the investigation of possibility of Al-alloy application for car-body parts the left front fender of the car YUGO was selected, which is now made of steel sheet metal Č0148P5 of 0,8 mm thickness. This pressed part was primarily selected because it is an independent pressed part which is connected to the car-body basis without welding. The drawing was performed in the factory „Zastava-Press workshop" in Kragujevac, on the mechanical press of double-action, in the conditions of whole-series production, for two Al-alloy sheet metals of 0,8 and 0,9 mm thickness.

On the basis of the comprehensive analysis of published papers and the experience of world car producers so far, and bearing in mind the domestic possibilities, the parts suitable for production, for which the material AlMg4,5Mn was projected, were selected. The alloy AlMg4,54Mn belongs to Al-Mg alloys whose main property is that they don't demand any thermal treatment before, during and after forming, but they are more difficult to be formed by deep drawing (table 1). The aluminum has a specific behavior in the area of plastic forming (fig.3).

The tension curve is not flat but it consists of a large number of local maximums and minimums. Fracture practically occurs without localization. Fig.4 shows the FLD for Al-alloy and steel. It can be observed that for steel significantly bigger values of critical strains were realized.

A. **Mechanical properties**					
angle/pr	R_p, MPa	R_M, MPa	A_{80}, %	n	r
0	278	153	19	0,252	0,55
45	267	145	21	0,258	0,859
90	272	150	23	0,258	0,592
$\overline{X}$	271	148	21	0,26	0,715
Strengthening curve (0°): $K = 152{,}9 + 305{,}9\,\varphi^{0{,}312}$, MPa					

B. **Chemical composition**								
element	M_g	M_n	S_i	F_e	T_i	C_u	Z_n	C_r
%	4,20	0,57	0,086	0,29	0,013	0,007	0,068	0,092

Table 1

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

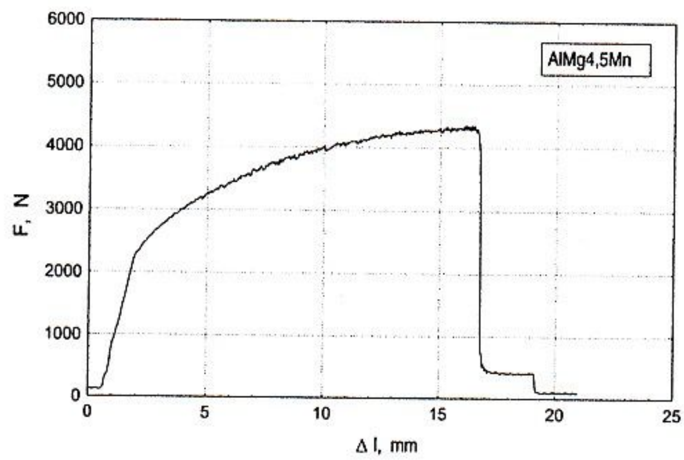

Figure 3: Tension curve

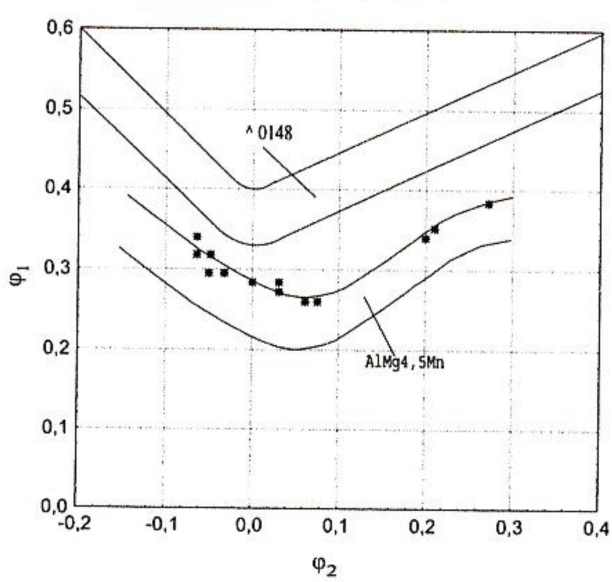

Figure 4: FLD for steel and alloy AlMg4,5Mn at monotonous forming

successfully obtained. 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.

Bearing in mind the spots on which the fractures would occur, two typical critical sections were selected – P and Z, fig.5.

For more thorough analysis of limit formability, a methodology of measuring grids was used. Before deep drawing, measuring grid, which consisted of circles of 5 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 forming 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 two sections of the pressed part is given in fig. 6 and fig. 7. The larger values of thinning for Al-alloys are obvious.

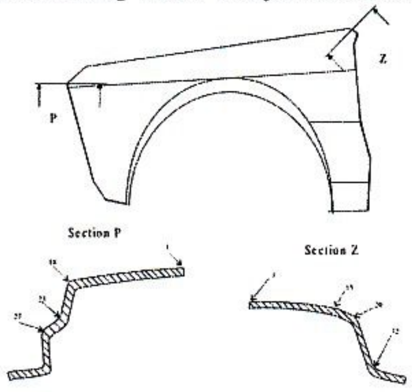

Figure 5: Schematic survey of the pressed piece with sections P and Z

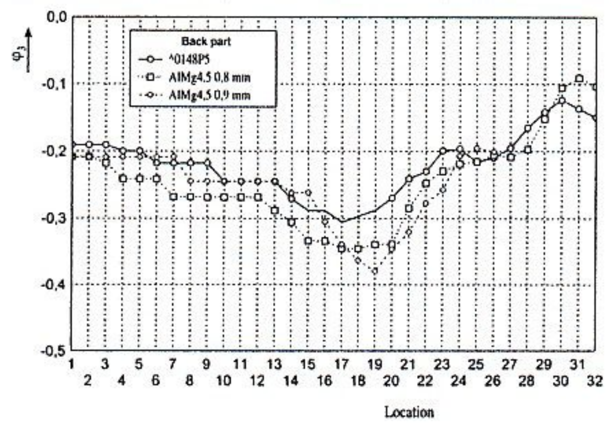

Figure 6: Change of thickness in section P

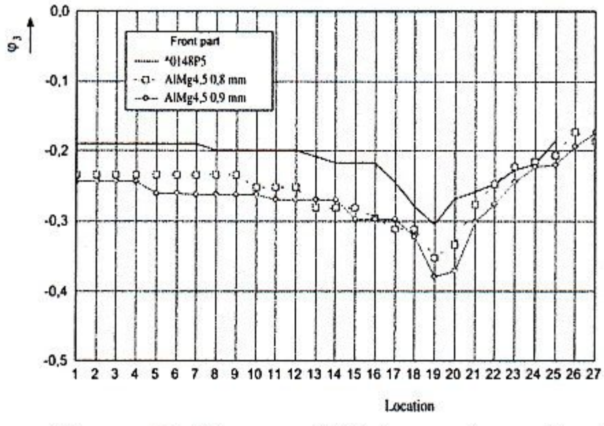

Figure 7: Change of thickness in section Z

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.

5. CONCLUSIONS

Small weight, resistance to corrosion and possibility for recycling represent the main properties of Aluminum as metal, which make it convenient for use in car industry.On the basis of performed examinations, laboratory and production investigations, we can conclude the following:

-correct selection of appropriate alloy for manufacture of the pressed piece is made difficult by insufficient knowledge on influence of certain factors onto the formability,
-the area of holding force is narrowed in comparison to steel, which influences the instability of formability factors,
-the damages on the piece surface appear easily (dints, scars),
-the alloys of Al are adhesively connected to the tool which causes the fracture of the piece,
-the ability of maintaining the shape is worse due to the small value of elasticity module,
-stiffness of the pressed piece, resistance to dints and impacts is worse,
-since Al is not magnetic the classic way of manipulation with piece is made more difficult, price is higher.

On the basis of the analysis of the performed trials we can say that the following defects appear most frequently:

- Appearance of crack on the piece. The fracture appears due to the small value of r-factor and elongation. In order to prevent the appearance of fracture it is necessary to increase the rounding radius on the drawer and die.
- Divergence from the given geometry due to the more prominent elastic recovery. On Al-alloys the recovery is more prominent due to the low value of elasticity module. In order to obtain the given geometry in construction of tools one should compensate the appearance of elastic recovery through appropriate bending angle.
- The appearance of galling. It appears due to impurities which exist on the surface of the sheet metal, smaller hardness and adhesion. In order to reduce the adhesion of the particles from the sheet metal surface onto the tool parts it is necessary to clean the sheet metal surface well, reduce the sliding friction by proper lubricants, by improving the quality of sheet metal cutting and coating of the tool surface by Cr.

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