FORMABILITY OF SHEET MATERIALS FOR LIGHT AUTOMOTIVE PANELS

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ABSTRACT
Reduction of fuel consumption and decrease of exhaust gases emission are among the most important working tasks for car producers from all over the world. Integration of the latest achievements in the area of science and technics has led to the realization of special results in this area, regarding motor construction and light car body making. With that purpose, in the last few years materials for manufacture of car bodies of reduced weight, such as high strength steel sheet metals, Al-sheet metals, titan and its alloys, sandwich and composite materials, tailored welded blanks, were used more and more. The paper gives survey of these materials, the application area, main advantages and disadvantages, description of formability parameters and results of researches in the area of boundary formability of these materials.

KEYWORDS: Sheet metal, Deep drawing, Formability, Light autobody

1. INTRODUCTION

Reduction of fuel consumption with simultaneous improvement of comfort, passive and active safety and similar, represents an important goal of all car producers. With that intent, during the last few years, materials for manufacture of reduced weight car bodies were increasingly more used; such material are: high strength steel sheet metals, Al-sheet metals, titan and its alloys, sandwich and composite materials and similar. Taking into consideration the long-term application of practically no other materials except low carbon steel sheets for that purpose, transition to application of rather new materials leads to many technological difficulties.
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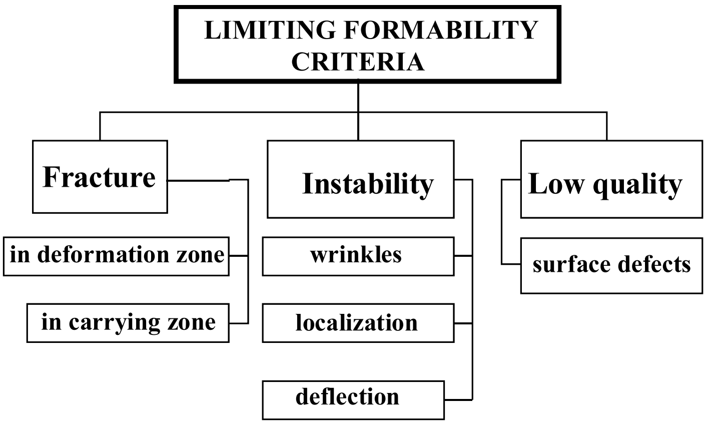

Figure 1: Main criteria for achieving limiting formability.

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When designing the technology for the process of metal forming by deep drawing, it is extremely important to know limiting formability, which can be defined as ability for realizing maximal strains in given forming conditions (stress-strain scheme, speed, temperature, tribological conditions etc.). In that way, limiting formability is one of delimiting factors when defining formability that also includes complex criteria for appearance of instability (wrinkles, localization −thinning, deflection), fracture etc (Figure 1 /1/).

In drawing of complex geometry pieces (e.g. car body elements), there are difficulties in formulating criteria for optimal exploitation of plasticity properties of the material being formed. Strain ratio in such pieces is different in certain points. In dependence on external influences, location of unstable forming zone can move. By applying experimental procedures on the basis of measuring grids, or numerical methods and simulations, it is possible to determine the realised strain ratio on one point, in wider zone or on entire piece surface. The obtained results represent basis for so called local or integral strain analysis. Access to realised strain distribution of the entire piece, that is a complex product, makes possible performing of much more complex analyses.

2. MATERIALS FOR MANUFACTURE OF LIGHT CAR BODIES AND THEIR FORMABILITY

Taking into consideration the exceptional application of thin sheet metals in car industry, as well as complexity of forming when producing car body parts, these materials will be considered in more details.

Reduction of fuel consumption and reduction of exhaust gases emission represent one of the most important developmental tasks for all cars producers worldwide. By integration of the latest achievements in the area of science and engineering, exceptional results in this field have been realised in engine construction and manufacture of light car bodies. Development and application of new materials for car industry, particularly car bodies, have been adjusted to general public demands by preservation of economic resources, energy and ecology preservation, passengers' safety and similar. With that intent, during the last few years, materials for manufacture of reduced weight car bodies were increasingly more used; such materials are: sheet metals made of high strength steel (HSS), Al-sheet metals, titan and its alloys, sandwich and composite materials etc.

In modern car industry, in car bodies manufacture, the following objectives are put in focus /1/:

- introduction of aluminium sheet metals,
- increased application of high strength steel sheet metals,
- increased application of zinc-coated sheet metals,
- reduced number of parts per automobile (pressed parts),
- reduced number of tools per pressed part,
- increased application of tailored welded blanks (TWB),
- need for zero defect quality production,
- need for production of exterior pressed parts with high-quality surface, without additional finishing,
- reduction of costs.

Out of the total car mass, 32% in average goes to car body . It is obvious that the reduction of car body mass contributes significantly to the reduction of total car mass. As a rule, reduction of car body mass can be realised by modification of car body structure concept and replacement of classic materials by light ones. The selection of material for car body is performed on the basis of several criteria given in Table 1 /2/.

Such materials make possible the weight reduction with fulfilment of requests for increased stiffness, which reduces fuel consumption and makes space for installing elements which make cars more reliable and comfortable.

Table 1: Weight reduction technology and its evaluation.

Weight reduction technology	***Application up to the present***	***Ideal form of weight reduction***	***Further weight reduction evaluation***			
			Mat. cost	Equipment investment	Weight reduction effect	Technical difficulty
Application of aluminium alloy sheet	Hoods and sunroof panels	All aluminium body.	+	+	o	×
Application of high−strength steel sheet (HSS)	Members and outer panels. Tendency for increased application as safety measures.	Members: R_M=590 MPa HSS. Exterior panels: R_M=390 MPa bake hardenable steel sheet.	+	o	+	+
Application of high r value steel sheet	Inner and outer panels.	As thin as possible, without posing vehicle performance problem.	o	o	+	o
Tailored welded blanks	Side panels, door inner panels, front side members, etc.	One sheet stamping by applying as thin sheet as possible.	o	×	+	+
Application of steel −plastic laminate sheet	Oil pan and inner panels.	Steel sheets as thin as possible. Thick plastics.	×	+	o	×
Laser irradiation	Currently being considered to new vehicles models.	Elimination of reinforcement parts by strengthening only the needed areas.	o	×	+	+

Signs - **o**: inexpensive and simple*;* **+**: average*;* **x**: extremly difficult

The basic concept when selecting a material for car body must comprise the following significant elements /3/: price, quality and quality stability, reliable purchase, functional properties (weight reduction effect, strength, resistance to corrosion), possibility for mass production (formability at forming, welding and ability for connecting, change of conventional manufacture method), waste utilization and recycling.

2.1. HIGH STRENGTH STEEL SHEET METALS

High strength steels have exceptional application in mechanical engineering, since they provide high stiffness with reduction of construction weight. High strength steel sheet metals (HSS) make possible the manufacture of car bodies of increased stiffness, smaller weight with satisfactory performances at standard endurance tests (energy accumulation at collision, oscillatory comfort etc). HSS were first used in the seventies, as a response to energy crisis and it has continuously been growing ever since, especially in Japanese car industry. It has been estimated that the present share of HSS of about 20% will increase as much as to 43%, whereat car body weight will be reduced for 10 to 20%. They are used for obtaining parts which do not request high strain ratio (fenders, hoods, members, reinforcements and similar). In Figure 2, the main materials out of which car body parts are made are marked /1/. It is obvious that more plastic materials have lower yield point and are more easily formed (standard material is low-carbon steel St 14 – domestic sign Č0148P5). In relation to classic materials, these sheets have unfavourable formability properties and higher price for the same weight.

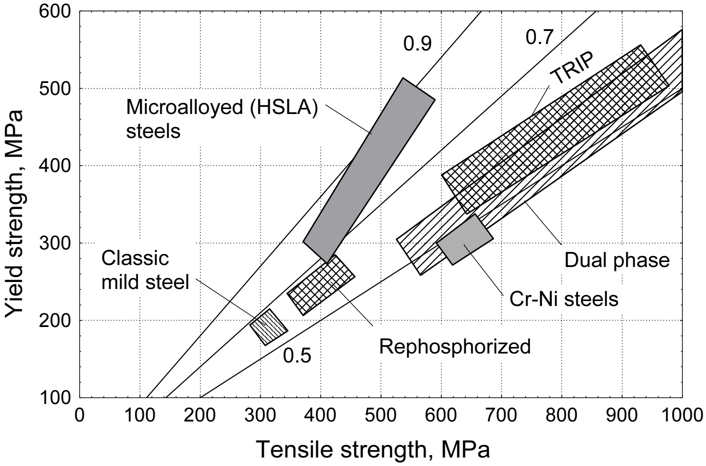

Figure 2: Properties of sheet metals used for car body.

Generally speaking, when using HSS, two cases can be distinguished: possibility for HSS application within the existing technology and designing of new technology, which basically includes HSS properties.

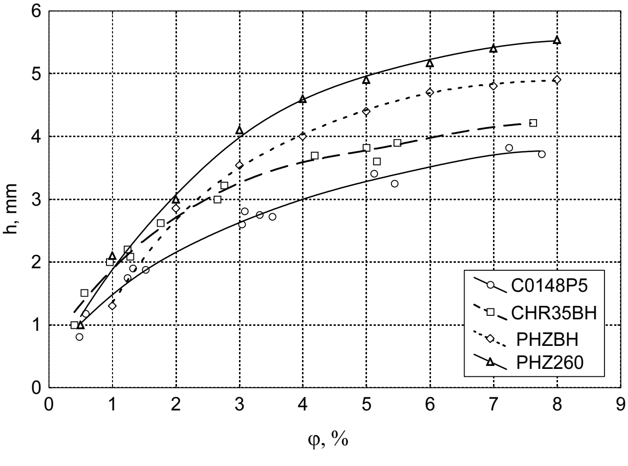

Figure 3: Dependence of wrinkles height on strain ratio.

The standard division of these steels is: conventional micro-alloyed, re-phosphorised, TRIP (Transformation Induced Plasticity), dual phase etc. Considering the prominent strength properties, in relation to classic mild steels, when forming HSS the deflection properties, i.e. ability to maintain shape and adjust to tool shape, become dominant. Deflection ratio can be expressed in different ways: by wrinkles height, ratio of given and realised measures and angles on pressed part, change of typical geometry parameter with punch travel etc. Figure 3 shows the experimental results at investigation of deflection according to so called Yoshida-test. Domestic and imported materials were investigated, within more comprehensive investigations of possibility for HSS application /4/ (PH-rephosphorised sheet metal, BH-sheet metal with Bake-hardening effect).

The main technological measures for reducing deflection are usually the following ones: achievement of additional tension in critical zones, change of material flow direction, optimization of blank shape and size, application of draw beads, change of punch geometry and lubrication scheme and similar.

2.2. AL-ALLOYS SHEET METALS

For car body parts, three groups of Al-alloys are mainly used: Al-Cu (series 2000), Al-Mg (series 5000) and Al-Mg-Si (series 6000). Small weight, resistance to corrosion and recycling ability are the most important properties that make Al-alloys suitable for application in car industry. One of specific properties of Al-alloys is that they can be obtained in a large number of tempers, considering the realised strain ratio or heat treatment during rolling. For replacing steel sheet metals, Al-alloy sheets of thickness increased for 20-40% are used .

The main properties of Al-alloys are: yield strength and tensile strength are lower compared to steel; elasticity module has three times smaller value compared to steel; elongation, particularly local, is small; normal anisotropy coefficient is small (below 1); relatively small hardness with surface which can be easily damaged /5/.

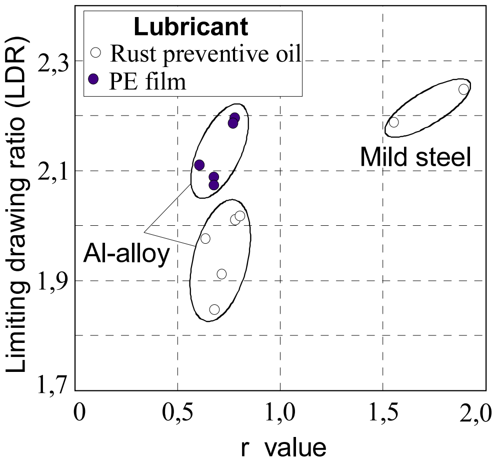

Figure 4: Indicators of Al-alloys formability.

The first application of aluminium in car construction dates back to the 20ties of last century (Rolls-Royce and Pomeroy), but the real industrial production of some car body parts (engine hood, doors, fenders and similar – parts which are "suspended" on a car body) started by application of aluminium alloys based on copper 2036-T4 and magnesium 5182-O in the eighties. At the world market, there are already cars whose entire car body is made of AL-alloys – (Audi A8, A2, Mazda AZ550, Porsche EXP, Honda NS-X and similar.). According to European publications, the total percentage of Al-alloys share in the following years will increase from 6 to 12%, that is from 70 to 120 kg in total per vehicle, or from 5 to 30 kg per car body. Japanese predictions are different and according to them the share of Al-alloys will be up to 15% in middle and lower class cars, and up to 25% in high performance cars /6/.

Due to reduced elasticity module, the problem of maintaining piece shape appears at forming (so called. "shape fixability"). These materials have good properties of uniform elongation, expressed by "n-factor", but due to small value of "r-factor" they are inferior in comparison to steel at forming by deep drawing, Figure 4 /3/. The difference in forming abilities is obvious from the position of curves in forming limit diagram, Figure 5 /6/.

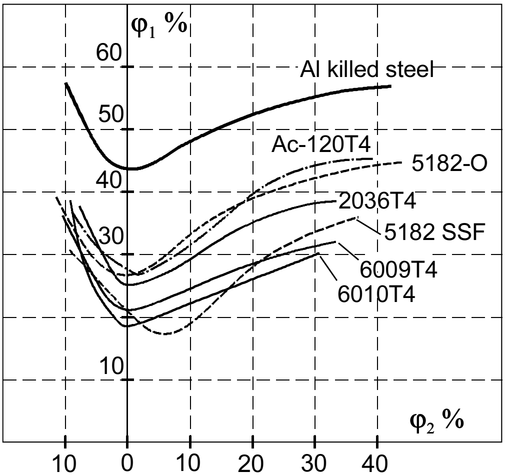

Figure 5: Forming limit diagrams.

In some Al-alloys, Luders lines, of so called types A and B, appear at forming, which influence considerably the quality of formed pieces surface, i.e. influence the aesthetics of exterior car body elements. Such materials can only be used for manufacture of interior car body parts. It is obvious that Al-alloys have reduced formability in comparison to steel. For investigation of these materials formability, a complete methodology developed for steel sheet metals application can be applied (mechanical properties, tests for pure deep drawing, stretching, forming limit diagrams, deflection tests and similar.). Tribological conditions have exceptional significance at forming of Al-alloys by deep drawing, mainly due to their small hardness and intensive binding of Al to steel.

2.3. STEEL- PLASTIC LAMINATE SHEET METALS

Steel-plastic laminate sheets (sandwich materials, composite materials) are very interesting for the manufacture of car body elements, and some types are already used in practice. In dependence on the thickness of the filling, sandwich sheet metals can be divided into the ones for weight reduction (light sandwiches) and the ones for vibration damping, Figure 6.

Light sandwich sheet metals have thicker filling layer than sheet metals for vibration damping, and can contribute to the reduction of construction weight up to 30%. Between sheet metals, there is a thermo-elastic filling, with good damping properties, i.e. with metal or graphite inclusions which improve weldability. In exploitation, at relative micro-movement of one sheet metal with respect to the other one, visco-elastic strain appears inside the filling as well as reduction of vibration energy in the system being dampened. Polypropylene, nylon or polyethylene are most often used for filling.

Strength and elongation properties, as well as general formability parameters, correspond to properties of elements of sandwich materials structure. Considering the highly prominent tendency to creation of wrinkles on flange of piece being drawn, it is necessary to increase blank holding force, that leads to the reduction of limit drawing ratio /3,7/. At bending, significantly small bending radii can be realised, with appearance of distortion in zone beyond straight parts of cast. This error appears due to differences in bending radii of upper and lower sheet metals and adhesion properties in the zone of filling and sheet metal connecting, and the size of error also depends on bending angle. Generally speaking, formability of these materials increases with the increase of shear adhesion strength. Measuring methods for determining this property have not been standardised yet; instead, investigations are performed in line with particular factory norms.

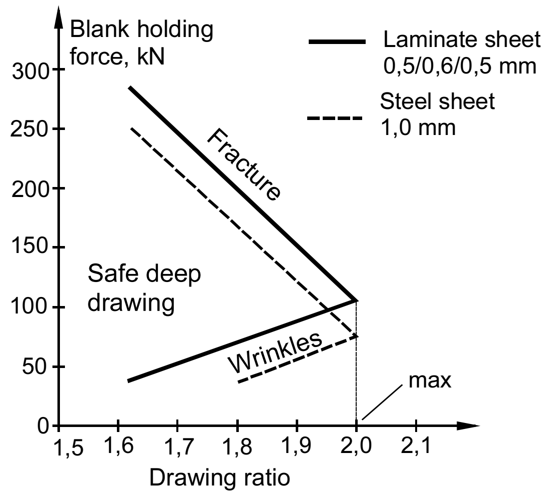

Figure 7: Work area at deep drawing.

Many parts can be made out of laminates without difficulties, in conditions valid for a standard steel sheet metal. Due to increase of blank holding force, appearance of fracture is possible. Also, the tendency to deflection, which depends on adhesion connection strength, thickness and nature of filling, is increased. A particular problem is a tendency of these materials to maintain shape achieved in deep drawing tool. In operations of punching and stamping out, due to separation of non-homogenous materials of very different strengths, tools undergo intensive wear. Inaccuracies at bending can be eliminated by applying sheet metals of different thicknesses and/or different strengths, by increasing shearing adhesion between sheet metals and filling, by additional calibrating and similar.

At same drawing proportions, it is necessary to increase the holding force , Figure 7 /7/. Limiting formability curves for sandwich materials are located in the area valid for steel sheet metals. Batter properties are related to the area of biaxial tension (stretching), and worse properties to the area of pure deep drawing.

Appearance of deflection on parts for interior installing, e.g. at car engine crankcase and similar, does not limit their installing. At exterior pressed parts, a particular problem regarding deflection can appear at paint baking and appearance of temperature strains.

2.4. FORMABILITY OF TAILORED WELDED BLANKS (TWB)

Due to development of computer technology and additional non-conventional forming procedures, such as laser welding, forming with the aid of liquid – hydroforming, obtainment of material surfaces by rolling with programmed roughness etc., conditions are made for basic change of technological concepts in the area of deep drawing. Classic approach in car bodies manufacture – point-to-point welding of a large number of pressed parts is replaced by drawing out of a unique blank made out of elements of different materials, different thickness and mechanical

properties jointed by laser welding (TWB). In this way, the number of tools for forming by stamping out and deep drawing is reduced, but a unique tool is made much more complicated. Also, formability parameters become more complex due to the following reasons:
- properties around the welded joint are changed, considering its hardness is up to three times bigger compared to the basic material;
- at forming of sheet metals of different thicknesses, tribological conditions in holder zone are of a particular importance;
- position of welded joint zone must be properly selected, considering the main directions of metal flowing etc.

Because of the exceptional requests regarding the forming system, these materials are normally formed on machines on which blank holding force can be controlled by a programme.

3. CONCLUSIONS

Generally speaking, difficulties at deep drawing of high strength sheets, Al-alloys, laminate sheet metals, tailored welded blanks etc can be classified in the following way:

- standard formability elements cannot be clearly controlled, which makes difficult the proper selection of the materials for particular parts,
- work area of blank holding force is changed, since it is necessary to achieve higher pressures on holder point (maintenance of shape) and at the same time reduce frictions on flange (avoid "galling"-appearances),
- materials which are additionally strengthened by aging are every convenient, and have good forming properties,
- considering surface sensitivity and non-magnetisms of Al-alloys sheet metals, it is necessary to give particular attention to their storing and manipulation (protective foils etc.).
- reduction of construction weight cannot be realised by abusing stiffness, resistance to sagging etc.

Solving of these problems can be achieved by development of new materials-alloys with increased formability, redesigning piece geometry (elimination of compressive stresses with increase of tensile ones), new forming technologies (control of blank holding force regarding intensity and holding zones in real time, hydroforming etc.), development and adjustment of methods for determining particular formability parameters (input parameters for control), improvement of lubrication technique and similar.

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