CRASHWORTHINESS STUDIES ON VARIOUS MATERIALS, FORMING PROCESSAND THEEFFECTSON VEHICLE BODY

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ABSTRACT

Crashworthiness has been a major criterion in making vehicles safe to be used and manufactured. There are many factors contributing in determining the level of crashworthiness, one is in determining the right type of material to be used and one in the consideration of process that can change the properties and characteristic of the material and design. This review paper discusses briefly on type of material that being used in car manufacturing today and the processes to form desirable shape of vehicle that can affect the material properties and thickness, thus, differ the value of crashworthiness of a vehicle. This review paper also intended to review about the type of materials and their properties used in manufacturing vehicles, to explore about manufacturing process that affects the thickness of the car body panel and to discuss the effect on change in vehicles structures properties and thickness with and without forming.

Keywords: Crashworthiness, Materials, Metal forming, Vehicle manufacturing, Vehicle safety, Lightweight design

I. INTRODUCTION

The ever-increasing varieties as well as complexity of vehicle body materials make this a field of interest and complicated technological development. A manager in die company, Jody N. Hall states in his slide presentation that there has been a shift at a fairly common range of mild steel as well as occasionally aluminium only 40 years past to the extensive array of sophisticated specifications apparent today [1]. ElahehGhassemieh from University of Sheffield agreed that steel has continued the predominant material throughout car bodies for over the century by means of keeping pace with the entire evolving car [2]. Improved corrosion-resistance, more refined mechanical properties, higher strength characteristics, and advanced manufacturing technologies have kept steel at the top in terms of content in the average vehicle on the road where it is estimated about 60% by weight today[2].

Nevertheless, in Akihiro Unishi et al technical report for Nippon Steel company dated January 2000 stated that the increased choice of more advanced kind of alloy has been recently utilized respect in order to properties and the fact that possibilities are achieved to scale back the percentage of steel utilized in today’s automobiles entire world [3]. Lena SmidfeltRosqvistattempted to say there are also has been a similar widening of choice for aluminium alloys and the increasing utilization of magnesium alloys, to achieve the target for lighter weight bodies to reduce fuel consumption, as by 10% weight reduction in passenger cars, the fuel economy improves by as much as 6–8% [4]; and attendant emissions, and also to increase performance which all of this criteria have been a focus for every cars manufacturers nowadays to being able to penetrate the market better than the competitors.

Vehicle body members for instance front side members, pillars and side sills needs to be designed to take in the kinetic energy efficiently throughout the car crash so as to secure occupants from the impact and penetration which in turn increases the crashworthiness of any vehicle are present by Richard Sturt et al paper [5]. POSCO Technical Research Institute paper published also agreed the design of the chassis itself plays a crucial role in protecting the occupants from having undesired consequences due to crash [6].Briefly, the type of materials implemented on the vehicle's chassis as well as its design contributes the vehicle crashworthiness. Lilehkoohi et al [26, 27] have conducted several simulations to investigate the effect of material on crashworthiness in side impact test and pole side impact test.

II. TYPES OF MATERIALS USED FOR VEHICLES CHASSIS

2.1 Steel

There are two kinds of steel that can be found, plain carbon steel and alloy steels.Under plain carbon steel, there are 3 more categories of steel which are low carbon steel also known as mild steel, medium carbon steel and high carbon steel [7]. Séblin. B et al point those out in a paper. Table 1 shows the type of carbon steel and their uses specifically for automobile component tabulated in an Industrial Education book volume 52 [8].

	Carbon Steels and Their Uses	
	% by weight of carbon in steel	Uses
Low carbon	0.05-0.20	Automobile bodies, buildings, pipes, chains, rivets, screws, nails,
	0.20-0.30	Gears, shafts, bolds, forgings, bridges
Medium carbon	0.30-0.40	Connecting rods, crank, pins, axles, drop forgings
	0.40-0.50	Car axles, crankshafts rails, boilers, auger bits, screwdrivers
	0.50-0.60	Hammers, sledges

Table 1: Carbon Steels and Their Uses [8]

Alloy steels are designed by combining steels with a number of other elements according to the strength needed per application. The other components are purposely blended with steel as to have properties that is not achieved by basic carbon steel.

A word by Tamarelli show the requirements for safety, efficiency,emissions, manufacturability, durability and quality at a low cost in automotive manufacturing can be satisfied by using Advance High Strength Steel, (AHSS) material [9]. The statement made by Akihiro Unishi also support the characteristic of AHSS which has high yield strength and high work hardening rate compared to conventional steel such as mild steel contributed in making of thinner design of components while maintaining the same load bearing capability[3]. Besides that according to Gan et al [10], the unique combination of material and mechanical properties from AHSS grades was formed by carefully selecting the chemical compositions and multiphase microstructures resulting from precisely controlled heating and cooling process. Moreover, ltan, T. state that the HF type of AHSS or can be call as boron steel which contain boron alloy ranging from 0.002 -0.005 % is the most commonly used in automotive industry [11]. Stainless steel is also a material of choice due to passivity and resistance to corrosion [2]. Some of the stainless steel grades suggested for automotive are as follows:

a) Duplex austenitic-ferritic stainless steel

b) Austenitic stainless steel

Property	Duplex Stainless Steel (1)	Austenitic Stainless steel			6061 Aluminium Alloy		High Strength Steel HSLA
		Annealed	C850(2)	C1000(3)	T4(4)	T6(5)	
Density: ρ(g/cm³)	7.8	7.9	7.9	7.9	2.7	2.7	7.83
Yield Stress: σ (N/mm²)	640	370	600	880	130	275	410
Specific Strength (N/mm²/g/cm³)	82	46.8	76	111.4	48.1	100	52.4

Figure 1: Specific Strength of Stainless Steels, 6061 Aluminium and High Strength Steel [2]

(1) In the solution annealed condition,

(2) In the cold worked condition C 850 (850<UTS (N/mm2)<1000),

(3) In the cold worked condition: C 1000 (1000<UTS (N/mm2)<1150),

(4) In the solution heat treated condition,

(5) In the precipitation heat treated condition

2.2 Aluminium

The aluminium is much more desired in car makers because of the lightweight properties that can be offered where as being mentioned before lightweight is very crucial in increasing efficiency and reducing fuel consumption to go further. On the other hand, the price tag of aluminium and cost stability are its main impediment to be used within large-scale sheet applications [1]. Ron Cobden et al talking about the properties of aluminium in their training module as lightness are the outstanding and best known characteristic of aluminium. The metal has an atomic weight of 26.98 and a specific gravity of 2.70, approximately 1/3 the weight of other commonly used metals; with the exception of titanium and magnesium [12]. Moreover, the addition of other metals inside the amounts commonly utilized in aluminium alloys isn't going to appreciably change the particular density, plus minus 2 to 3 % except in the case of Lithium alloys where the density of the particular alloy is reduced by nearly 15%. [4].

Weight is vital for all purposes involving motion. Saving weight leads to more payload or perhaps greater economy in terms of operation. Saving excess weight also saves power, reduces vibration, and improves the actual performance of reciprocating and also moving parts. Low weight combined with the high strength possible with special alloys has placed aluminium as the major material for aircraft construction for the past sixty years [12]. A book published by NPCS shows that aluminium usage in automotive applications has grown substantially within past years. A total of about 110 kg of aluminium: vehicle in 1996 is predicted to rise to 250 or 340 kg, with or without taking body panel or structure applications into account, by 2015 [13].

An addition criterion of lightweight aluminium metal is that aluminium features a higher resistance in order to withstand corrosion than several metals owing on the protection conferred with the thin but intense film of oxide

[2]. This oxide layer is always present on the surface of aluminium in oxygen atmospheres. Fig 2 shows the degree of corrosion and its effect on strength in two different environments.

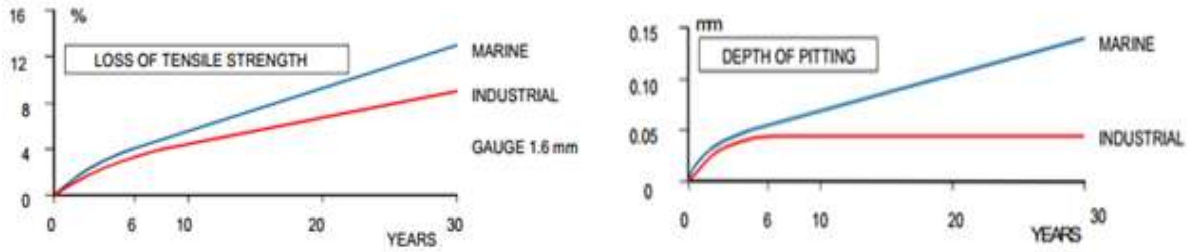

Figure 2: Pitting Corrosion Behaviour of 3103 Mill Finish Aluminium Sheet [12]

2.3 Magnesium

Magnesium is 33% lighter than aluminium and 75% lighter than steel/cast-iron components [2]. The corrosion resistance of modern, high-purity magnesium alloys is better than that of conventional aluminium die-cast alloys [13]; but magnesium components possess many mechanical as well as physical property disadvantages that need unique design intended for application to automotive products. The disadvantages regarding magnesium alloys are usually high reactivity inside molten state, inferior fatigue and creep when compared with aluminium and galvanic rust resistance [2]. Although it's tensile yield strength is about the same, magnesium has lower ultimate tensile strength, fatigue strength, and creep strength compared to Aluminium. The modulus and hardness of magnesium alloys is lower than aluminium and the thermal expansion coefficient is greater [11]. Even so, it should possibly be noted that appropriate ribbing and helps often can triumph over the strength as well as modulus limitations.

Despite the above issues, Mark Easton point out that magnesium alloys have distinct advantages over aluminium that could not be dismissed. These include better manufacturability, longer die life and faster solidification due to lower latent heat [14]. Therefore more castings can be produced per unit time compared to aluminium.Magnesium components also have higher machinability which its component can be produced with improved dimensionality and surface quality, and smaller draft angles compared to aluminium [2].

Property	Magnesium	Aluminium	Iron
Crystal Structure	hcp	FCC	BCC
Density at 20ºC (g/cm³)	1.74	2.70	7.86
Coefficient of thermal expansion 20-100ºC (*10⁶/C)	25.2	23.6	11.7
Elastic modulus (10⁶ MPa)	44.126	68.947	206.842
Tensile strength (MPa)	240	320	350
Melting point (ºC)	650	660	1.536

Figure 3: Properties of Mg, Al, Fe [2]

III. MANUFACTURING PROCESS THAT AFFECTS THE THICKNESS OF THE CAR BODY PANEL

The properties of formed vehicle structures have been effected and changed by such as work hardening and non-uniform thickness distribution resulted from forming process. Crash analysis regarding vehicle structures while using forming effects, causes different results coming from those without this forming effects [5]. In order to obtain reliable crash simulation, crashworthiness of vehicle structures should be evaluated considering the consequence of stamping and forming in addition to the dynamic properties regarding materials [6].

3.1 Hydro Forming

The hydroforming process results in very significant left over thickness changes as well as work hardening, and will have a major impact on crash results. Hydroforming uses fluid pressure rather than the punch as comparing a conventional tool set in order to create the component into the desired shape from the die is an illustration by A. Kocańda et al [15]. Gary Morphy defined the hydroforming as a system that uses high internal pressure so that the tube hoop stress at the corner radius is higher than the material yield strength [16]. Basically there are 2 main hydroforming methods: tube hydroforming and sheet hydroforming.

Tube hydroforming process as mentioned by F.J. RípodasAgudo et al [17] is a tube that will first being placed in a closed cavity of a forming dies. Once the ends of the tube are sealed, the tube is filled and pressurized with hydraulic fluid. The internal pressure forces lead the tube to form into the shape of the tool cavity. Nader Abedrabbo et al and Mikael Jansson both agrees [18, 19] that tube hydroforming technology has drawn increasing attention in the automotive industry because of its enormous advantages which include part consolidation, weight reduction due to improved part design, improved structural strength and reduction in the associated tooling and material costs. However, a journal by Peng Jun-yang et al [20] says that there are disadvantages due to many variables, such as loading paths, material formability and tribological conditions, which limit its applicability and influence parts failure such as excessive thinning, wrinkling, and buckling.

Sheet hydroforming is simply a sheet metal part formed by water pressure generated by the punch drawing the sheet into a pressurized water chamber [15]. Sheet hydroforming is further classified by Hong Huh et al [6] into sheet hydroforming with a punch and sheet hydroforming with a die, depending on whether a male (punch) or a female (die) tool will be used to form the part. Hydroforming allows 50% less material thinning than for conventional deep drawing is one of hydroforming advantage mentioned by Seward E. Matwick[21]. The main drawback to sheet hydroforming is its longer cycle time which causes the process to be cost prohibitive at high volumes[21].

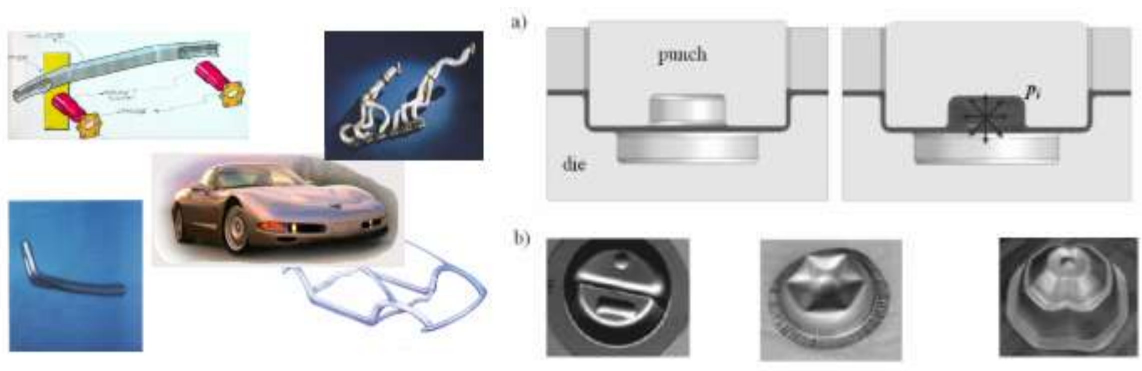

Figure 4: (A) Typical Hydroformed Components in a Car Including (B) Scheme of Sheet Hydroforming and Examples of Products [15]

3.2 Stamping

Stamped parts show much less sensitivity, because areas which are work hardened would also normally be thinned from the stamping process; each effect might approximately cancel one another [15].Stamping presses and stamping dies are tools accustomed to produce high level sheet metal parts. These parts achieve their shape from the effects of the die tooling. Production stamping is generally performed on materials .020” to .080” thick, but the process also can be applied to foils as thin as .001” or to plate stock with thickness' approaching 1.000” [6]. Nowadaysthere are 2 types of stamping, one is hot-press stamping and another would be cold-press stamping.

TaylanAltan explained about hot stamping, in a magazine where in hot stamping, forming and hardening are combined in a single operation. There are two different methods, one is direct and one is indirect. In the direct method, the blanks are austenitized at temperatures between 900 and 950 degrees Celsius for 4 to 10 minutes inside a continuous-feed furnace and subsequently transferred to an internally cooled die set via a transfer unit [24]. indirect hot stamping provides for a part to be drawn, unheated, to about 90 percent to 95 percent of its final shape in a conventional die, followed by a partial trimming operation. As for cold stamping, it is similar to hot stamping but the difference is that it does not involve any conduction of heat on the blank and die. In a paper by HandeGüler et al [25] that differentiate between hot press and cold press, based on the simulation that had been done, hot press stamping is safer than cold press stamping.

Figure 5: Example of Stamping Product for Vehicle Manufacturing

IV. EFFECT ON CHANGE IN VEHICLES STRUCTURES PROPERTIES AND THICKNESS WITH AND WITHOUT FORMING

T. Dutton et al [22] proposed that metal forming processes result in a number of changes in the material properties of a formed component. The initial blank material is subjected to large deformation during forming which results in changes in the thickness and yield point of the material. A forming analysis done by T Dutton et al] shows the results of the hydroforming process, indicating thickness strain, plastic strain and residual Von Mises stresses before and after springback. It was notable that the overall change in thickness was not dramatic with thinning mostly restricted to the outside of the bends; axial end feel causes thickening concentrated at the rail ends. However, a large amount of material experienced considerable work hardening, as indicated in Fig 6 (b), with many areas showing more than 10% strain. The average thickness change measured from the tensile test specimens was –5.1% among 24 specimens cut from the material.

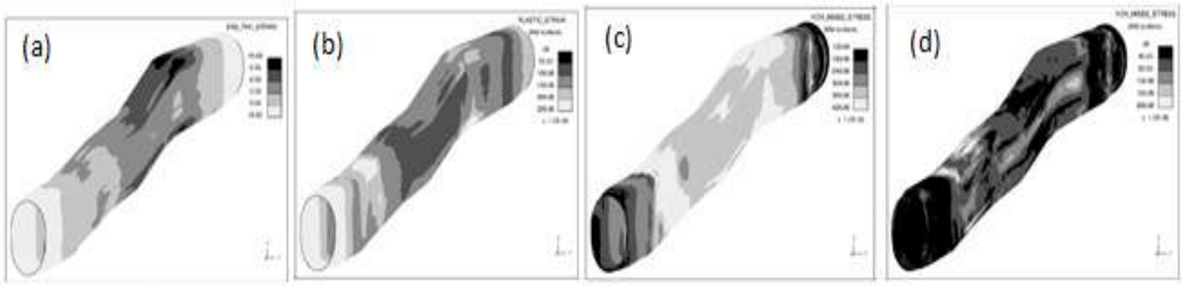

Figure 6: Results Of Forming Analysis (A) Thickness Strain (B) Plastic Strain (C) Von Mises Stress (Before Springback) (D) Von Mises Stress After Springback) [22]

A crash analysis has been carried out by another researcher on determining the crashworthiness in four different cases. One without considering fabrication effects; one with considering the thickness distribution only; one with considering the effective plastic strain distribution only; and one with considering all fabrication effects[6].

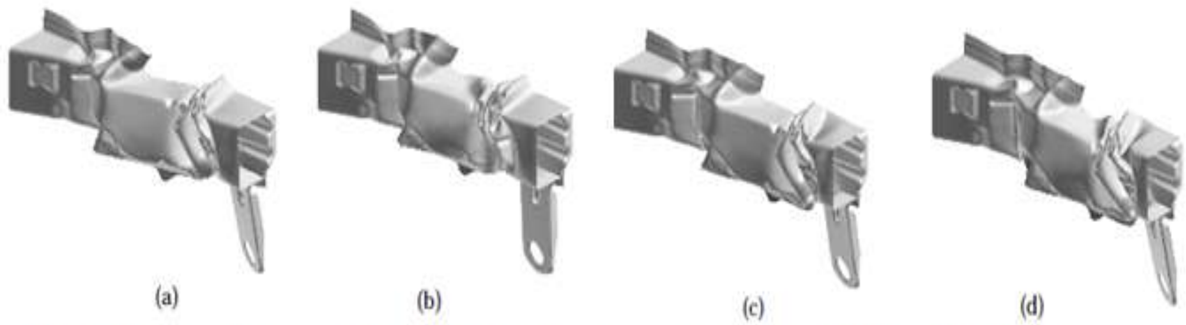

Figure 7: deformed shapes of the front side member at 30m/sec: (a) without forming histories; (b) with the thickness distribution; (c) with the effective plastic strain distribution; (d) with all forming histories [6]

The end result in Fig. 7 shows that the first as well as second ones deform greater than the third and fourth ones. The third one with taking into consideration the effective plastic strain distribution would be the strongest while the other one with consideration of the thickness distribution would be the weakest. It is because that the effective plastic strain distribution plays a role as reinforcements in crash with the increased flow stress and the thickness distribution plays a role as defects in crash because of thinning due to stamping [6].

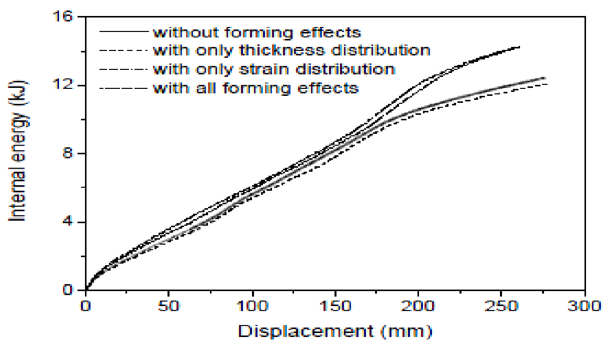

Figure 8: Comparison of the Energy Absorption With Respect To the Displacement in the Front Side Member during the Crash for 30 Milliseconds [6]

Fig. 8 demonstrates in which energy absorption increases remarkably if the effective plastic strain is considered and decreases slightly if the non-uniform thickness distribution is regarded. The energy absorption from front side member features a larger value whenever all forming effects are thought than the one without forming impact. The difference is 5.3 % at the crushing distance of 100 mm, 10.2% when the crushing distance is 200 mm, and 17.3 % when the crushing distance is 250 mm [6].

According to a paper made by Dr. Kim Kose et al [23], a simulation is done by considering the effect of plastic deformation of a metal due to the history of forming while doing an analysis for better result. It is known that the material state is changed by every step in the production process. Thus, the behaviour of the final part depends on every previous step. In the paper, they were using upper shell of a steering knuckle made by thick steel sheet as the subject. Fig. 9 shows that in the load-displacement curves, it can be easily seen that the inclusion of the forming history has a significant effect on the strength of the part. In this example the deviation is about 30 percent. This concludes that the history forming process affects the behaviour and strength of a component thus, differ the value of crashworthiness.

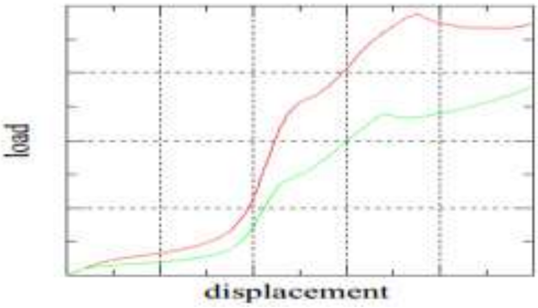

Figure 9: Load Case And Simulated Load-Displacement Curves With (Red) And Without (Green) Plastic History [23]

V. SUMMARY

This review paper can be summarizes in words that describes crashworthiness is not all about obtaining the best results is crash test but it is to investigate the root cause of the manufacturing where there are always room for improvement. In auto industries, there are always a need on chasing the lightweight design and mass of the product as to achieve the specified regulations as well as keep on decreasing the fuel consumption. This demands feature not only can be achieved using expensive lightweight material such as aluminium and magnesium, it also can be achieved using steel as there are lot on improvement done to making steel as lightweight as possible while maintaining the needs of strength. The characteristic and material properties of earth compound have been studied and new development have been made and improved to make a car structure more crashworthiness. It can also be conclude that material shape forming affects the structure analysis and material properties. Thus, the crashworthiness assessment has to be carried out with the consideration of the fabrication histories of auto-body members for accurate and reliable evaluation. This is due to the changes and movement of the metal grain in atomic level and the thickness distribution along the metal after being forming with extreme forces and conditions. Many research that have already been made to make the automotive world a better place in terms of methods uses and material selection just as to make sure that safety is the priority matter in designing vehicles for the people.

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