ENERGY ABSORPTION OF IMPACT DAMPER

BALAMURUGAN A/L ANNAMALAI GURUNATHAN

UNIVERSITI TEKNOLOGI MALAYSIA

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To my beloved father, late mother, wife and daughter

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ABSTRAK

Bahagian depan dan belakang kenderaan perlu dilindungi supaya pelanggaran pada halaju rendah tidak atau kurang berkesan dalam mengakibatkan kerosakkan struktur kenderaan. Tenaga kinetik yang berpunca daripada pelanggaran berhalaju rendah dianggarkan sekitar 1000 J. Jika tenaga ini tidak dapat diserap dengan betul, ia boleh merosakkan bumper dan bahagian lain yang dipasang bersebelahan dengannya. Dalam projek ini, tiub bulat telah digunakan untuk menyerap tenaga yang berpunca daripada pelanggaran berhalaju rendah pada 4 km/j. Ketebalan dan panjang tiub yang memberikan tegasan lilitan kurang daripada tegasan maksimum telah dipilih. Kaedah analitikal dan berangka telah digunakan untuk memilih ketebalan dan panjang yang sesuai. Model pepejal tiga dimensi bumper dan tuib bulat dibangunkan dan dipasang menggunakan rekebentuk berasaskan komputer. Simulasi dilakukan keatas model bumper dengan daya bernilai 1333 N yang diperolehi berdasarkan kepada ECE/324 Regulation No.42. Simulasi linear dan bukan linear dilakukan. Keputusan menunjukkan bahawa tuib bulat dapat menyerap tenaga dengan baik.

ABSTRACT

The front and rear of the vehicle should be protected in such a manner that low speed collisions will only damage the vehicle slightly, or not at all. Kinetic energy due to the low speed collision could be as high as 1000 J. If this impact energy is not dissipated properly, it could damage the bumper and other components attached to it. In this project, circular tube was investigated to absorb the impact energy during low speed collision at 4 km/h. The thickness and length that gives hoop stress lower than yield strength of the material is selected. . Both analytical and numerical methods were used to find suitable thickness and length of the tube. Solid assembly model of the bumper, front cross member and circular tubes were developed. The bumper is simulated with impact force of 1333 N based on ECE/324 Regulation No.42. Both linear and non-linear simulation was carried out. Results show that circular tube exhibit good energy absorption behaviour.

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A	-	Cross sectional area
b	-	Base (Width)
D	-	Diameter
E	-	Modulus of elasticity
E_K	-	Kinetic energy
F	-	Axial force
F_a	-	Average crush load
$F_{i\,max}$	-	Initial peak load
G	-	Modulus of rigidity
h	-	Height
I	-	Moment inertia of area (Second moment of inertia)
k	-	Spring stiffness
L	-	Length
m	-	Mass
M	-	Bending moment
N	-	Normal force
P	-	Transverse (Lateral) force
q	-	Shear stress
t	-	Thickness
U	-	Total strain energy

U_s	-	Shear-strain energy
U_f	-	Flexural-strain energy
U_c	-	Circumferential-strain energy
v_2	-	Velocity before collision
v_1	-	Velocity after collision
V	-	Shear force
y	-	Distance from neutral axis
δ	-	Displacement
δ_f	-	Flexural deformation
δ_s	-	Shear deformation
δ_c	-	Circumferential deformation
θ	-	Angle subtended by an arc at center of circle
σ_c	-	Circumferential (Hoop) stress
σ_{c1}	-	Tensile circumferential stress
σ_{c2}	-	Compressive circumferential stress
σ_{cn}	-	Circumferential stress at neutral axis
σ_1	-	Maximum tensile circumferential stress
σ_2	-	Maximum compressive circumferential stress
σ_x	-	Axial stress
υ	-	Poisson’s ratio
Δt	-	Time interval during collision

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CHAPTER 1

INTRODUCTION

1.1 Automotive Bumper and Energy Absorber

The front and rear of the vehicle should be protected in such a manner that low speed collisions will only damage the vehicle slightly, or not at all. This requirement is outlined in ECE/324 Regulation No. 42 of UNECE [1]. For this purpose front and rear bumpers were invented. The uses of bumpers has evolved from being a mechanism placed on the front and rear of the car to protect the body and safety features of a motor vehicle from damage due to a low speed collision to a decorative ornament designed more for the aesthetics of the motor vehicle rather than the actual functionality. The study carried out by Federal Motor Vehicle Safety Standards and Regulations (FMVSS) highlights how the present day bumpers on motor vehicles are connected to the fenders rather than the frame of the motor vehicle where it would be of more use and steady during a low speed collision. The study also shows how some automobile manufacturers have tried to produce shock absorbent bumpers using shock absorbent resilient materials.

As highlighted above, the styling of the bumper has become more important than the structural design of the bumper. Nevertheless, the standards and regulations governing the design of the bumper should not be compromised in any circumstances. The same goes for the correct selection of the bumper material. Any attempt to by pass the standards of regulations and material selection would badly affect the structural integrity as it would be next to impossible to provide protection neither to the vehicle body nor the occupant during a crash.

In the design of automobile parts and assemblies, components must be positioned within tight tolerances. This tight tolerance is a must to preserve the automotive aerodynamics and functionality of components with respect to each other. Furthermore, the support structures must not deform these components by applying unnecessary stresses. Therefore, the components must be kinematically constrained. Components are often supported on flexures, elastic elements which are relatively stiff in one direction and compliant in the other directions. Because these flexures are elastic and typically have negligible damping, vibration of the components relative to the support structure becomes a problem. Therefore, a method of introducing damping into the system must be found. The impact energy absorber, also known as the bumper energy absorbers (EA) was invented on this basis.

Much of the design and development of the modern energy absorber is dedicated to protecting occupants or reducing vehicle damage during a crash. Although the primary function of the vehicle body structure in this respect is to dissipate the kinetic energy of the vehicle, effective protection depends upon careful management of this energy in order to achieve the optimum collapse mechanism.

Most automotive energy absorbers that are on the market today are designed to meet safety regulations with respect to individual geographic locations. North American markets will require that the design should satisfy FMVSS regulations that require the energy absorbers just to protect the car. The European and Asia-Pacific markets have a different set of requirements that focuses also on the safety of the pedestrian. However, the difficulties of designing a bumper system that is rigid enough to protect the vehicle and, at the same time, compliant enough to protect a pedestrian raise questions as to whether these ideas are compatible.

1.1.1 Types of Impact Energy Absorber

There are two types of energy absorbers widely used in the automotive industry. The shock absorber type or the hydraulic design is a telescopic energy absorbing cylinder mounted between the front bumper and front cross member of the chassis. On the other hand the honeycomb type or the cell block deformation design has collapsible cells embedded in the bumper structure.

1.1.1.1 Shock absorber design

This energy absorber which looks like a shock absorber, functions as a connecting member between a bumper and front cross member for the purpose of damping the shock loading during a low speed collision between the motor vehicle and an obstacle. Under bumper impact situation these energy absorbers are loaded in compression or tension as the bumper moves from a designed outer position toward the vehicle body and are operative to absorb the energy of the impact. After impact, these energy absorbers recover at various rates to return the associated bumper assembly toward its original pre-impact position.

Figure 1.1 shows how the two absorbers are located between the front cross member and the front bumper reinforcement. During a front-end impact, the energy absorbers shorten, just like telescope-type shock absorber. Following the impact, if the impact is not beyond the designed limits of the energy absorbers, they return to their original length.

Figure 1.2 is an external view of an energy absorber. Figure 1.3 is a sectional view of the energy absorber in its normal extended position. In Figure 1.4, the absorber is shown in the extended position at the start of impact. The impact forces the piston tube to the right as shown in Figure 1.5. This action forces the hydraulic fluid to flow around the metering pin and through the orifice in the end of the piston tube. As the piston tube continues to move, the flow of hydraulic fluid into the piston tube pushes the floating piston to the left. This compresses the gas in the piston tube, as shown in Figure 1.5.

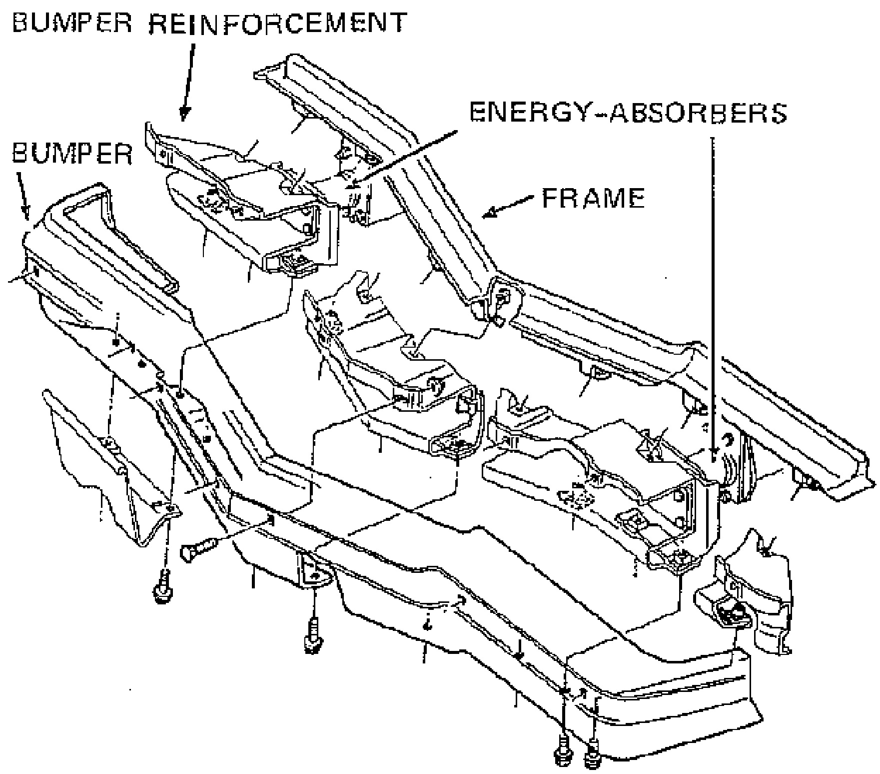

Figure 1.1 : Location of components in a front bumper system using two Energy Absorbers
(Courtesy of Automotive Plastic Parts, 1998)

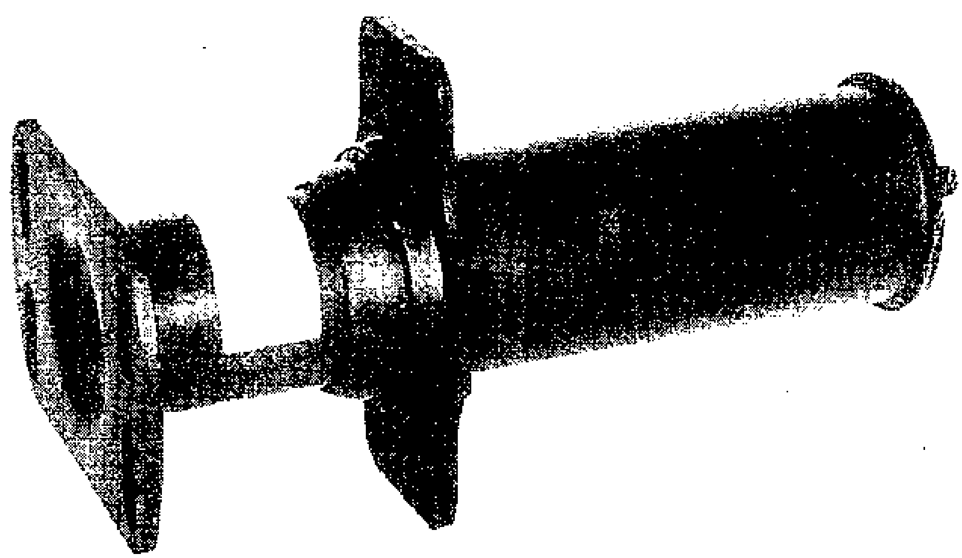

Figure 1.2 : Energy absorber
(Courtesy of Automotive Bumper Material and Design, 2004)

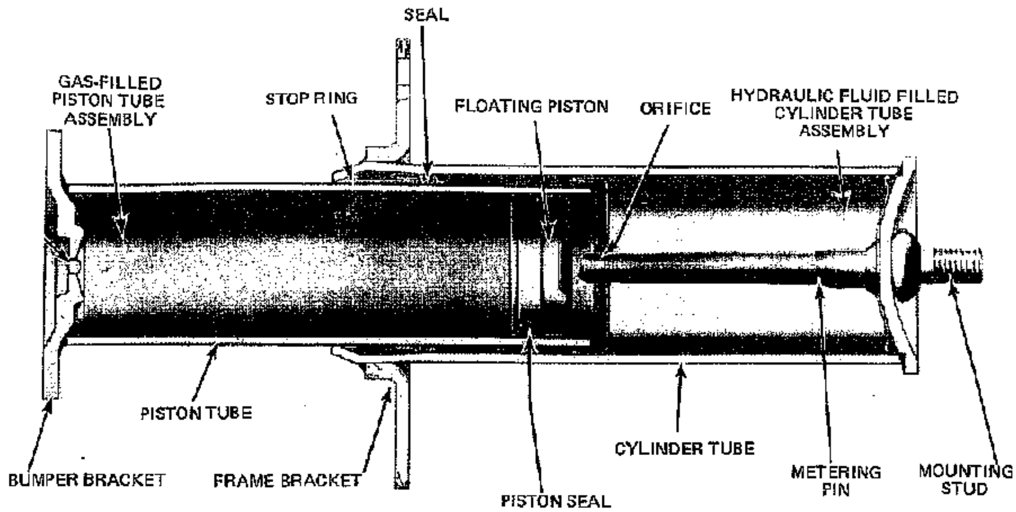

Figure 1.3 : Sectional view of the energy absorber in the extended position
(Courtesy of Automotive Bumper Material and Design, 2004)

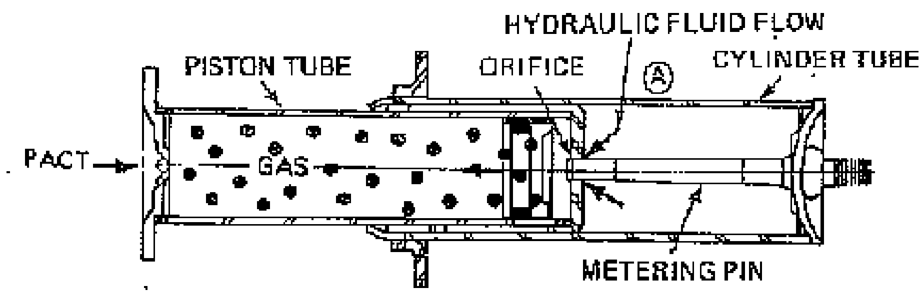

Figure 1.4 : Energy absorber in the extended position (pre-impact)
(Courtesy of Automotive Bumper Material and Design, 2004)

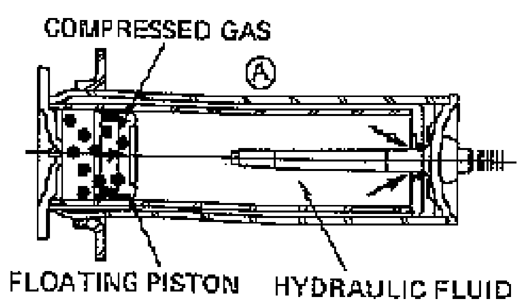

Figure 1.5 : Energy absorber in the shortened position (post-impact)
(Courtesy of Automotive Bumper Material and Design, 2004)

1.1.1.2 Honeycomb design

The honeycomb is a type of bumper that is made with the intention of absorbing forces exerted during a low speed collision. According to the National Highway Traffic Safety Administration (NHTSA) bumper standards, a low speed collision is pegged at a minimum of 1 km/h to a maximum of 8 km/h; in this case the Honeycomb Bumper Inventors (Angelo F. Carbone, Clinton F. Egerton and Emmanuele Fallacaro), claim the bumper can absorb the force exerted in at a low speed of between 12 km/hr to 16 km/hr. The honeycomb bumper is a combination of an impact force absorbing core (honeycomb structure), made of either plastic, metallic materials or paper material, and a shell or cover for the structure which can also be made from the same materials as the core.

The core is a honeycomb like structure made up of many cells; it is the impact force absorbing mechanism during the low speed collision. A cell is a hexagonal shape or any other suitable geometric shape which is extruded for a certain length; the cell is hollow and thus maintains a certain thickness throughout the extrusion. The material used for the core can be polypropylene, polyvinyl chloride, polyurethane, polyethylene, aluminium or paper fibres. The core can be manufactured using any conventional manufacturing process that will allow for its production in planar form. Once the core is produced, it should have no '*memory*' meaning there should be no internal forces in the core forcing it to fold – because the structure uses a hexagonal shape, the core can fold about the corners due to internal stress and strain.

The shell is the outer casing of the core, which will be shaped to case the core as well as maintain the style and design of the motor vehicle. The materials that can be selected to fabricate the shell can be fabricated using rubber, Mylar material or any of the materials that can fabricate the core.

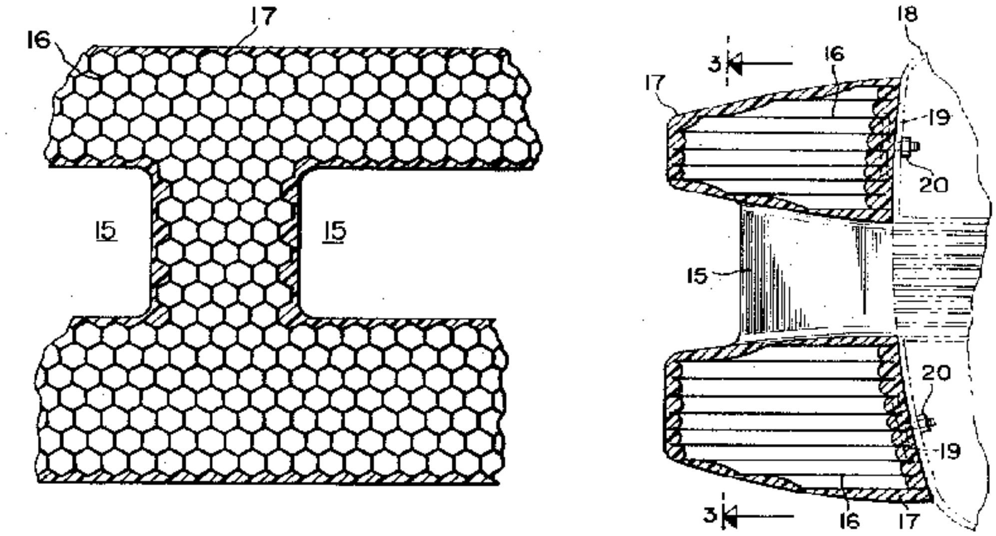

Figure 1.6 : [Left Side] - Core Cross Sectional View.
[Right Side] - Core Top View.
(Courtesy of AB Volvo, June 1978)

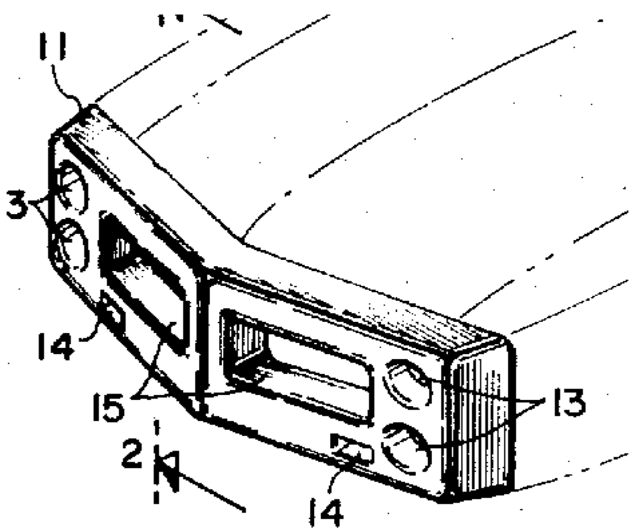

Figure 1.7 : Honeycomb Bumper – A combination of the Shell and the Core
(Courtesy of AB Volvo, June 1978)

The working principle behind the Honeycomb Bumper is analyzed from a single extruded hollow cell. When force is exerted onto the cell, deformation occurs and this deformation absorbs a certain amount of force. In the case of the core, there are hundreds or maybe thousands of cells that use the same concept as the single hollow extruded cell, thus the sum of the overall amount of force absorbed during a low speed collision is high, enabling the Honeycomb Bumper to absorb a considerable if not all the force exerted during a low speed collision at a speed of 16 km/h.

Evaluating the Honeycomb Bumper, it is a cost effective way of developing an impact absorbing bumper that is light in weight, high in strength and it can be fabricated to suite the style and design of the motor vehicle. However the Honeycomb Bumper would have to be replaced should a motor vehicle be involved in a low speed collision because the cells are not retractable or do not move back into position..

1.2 Bumper standards

ECE/324 Regulation No. 42 [1] provides guidelines and arrangements concerning the approval of vehicles with regard to the front and rear protective devices based on low speed impact test procedure. According to this regulation, bumpers, which are exterior protective element located at front and rear ends of vehicles, are designed to allow contacts and small shocks to occur without causing any serious damage in a low speed collision. First of all the surfaces of the bumper which are most likely to come into contact with other objects shall be covered by, or made of rubber, or equivalent material, the hardness of which shall not exceed 60 Shore A. The impact test is carried out in accordance with the conditions and procedure specified in [1].

Based on [1], there are two types of impact test that should be performed on the front and rear bumpers. The first test is the longitudinal impact test which involves two impacts on the front bumper and two impacts on the rear bumper. On each bumper, one impact is tested with vehicle unladen weight condition while the other is tested with vehicle laden weight condition. The speed of the impactor should be 4 km/h.

The second test is known as corner impact test. This test also consists of two impacts on the front bumper and two impacts on the rear bumper. The first impact is made of unladen weight impact at one corner of the front bumper and the rear bumper. The second impact is aimed at the other corner of the front bumper and the rear bumper under laden weigth condition. In this test, the vehicle should be impacted at a speed of 2.5 km/h.

The impactor could be either secured to a moving barrier or form part of a pendulum. The moving barrier must be rigid enough and should not be deformed by the impact. For the impact via the pendulum, the plane of pendulum must always remain parallel with its axis of rotation. The lighting and signaling devices, hood, trunk lid, doors, fuel and cooling systems, exhaust system, propulsion, suspension, tyres, steering and braking systems should be operable in the normal manner after the impact test.

1.3 Bumper material

The bumper is designed to have optimal mechanical properties which improve the pedestrian protection and low-speed collision as well. The bumper essentially consists of a cover, an absorber, arranged beneath to the cover and mounting elements to connect a cover and absorber to the vehicle body.

The optimal mechanical properties to improve the pedestrian protection and low speed collision are achieved using general principals of stiffness, in which the stiffness of the lower portion of the bumper in its mounted position is increased relative to the upper portion of the bumper. By making the lower portion of the bumper which is directed forwardly into the direction of the driving stiffer, the impact force in case of collision with a pedestrian is concentrated at the lower portion of the bumper.

Bumpers in the earlier years were made of steels or heavy metals. Nowadays, bumpers are made of rubber, plastics and other light painted and resilient materials. Some bumpers now features crumple zones which allows the material to flex upon collision in order to absorb the impact and returns to its original shape.

The majorities of modern cars are made of thermoplastic olefins (TPOs), polycarbonates, polyester, polypropylenes, polyamides, or blend of these with, for instance glass fiber for strength and structural rigidity. Other than that, there is also a rubber bumper or elastomeric bumper can be made from either natural or synthetic rubber.

Bumper systems usually include a reinforcement bar plus energy-absorbing material, such as polypropylene foam. Better bumpers often have hydraulic shock absorbers instead of, or in addition to, the foam. The most widely used energy-absorber construction is made from expanded polypropylene foam (EPP). Honeycomb energy-absorber, which are made from ethylene vinyl acetate (EVA) copolymer, are also still used on some other cars. This has been discussed in Sections 1.1.1.1 and 1.1.1.2.

The replacement of metal in bumper to reduce the weight of the vehicle, reduce cost and improve petrol consumption has follow several stages mostly directed at the bumper fascia and improving polypropylene, polyurethane, thermoplastics, elastomers, PC/ABS and PC/PBT blends.

Bumpers fascias are hardly 3 mm thick and the key physical properties are for flexibility and shock resistance. Today, the mostly used materials are polypropylenes, due to compromise between cost and mechanical properties. Other thermoplastics used for fascias have mainly been alloys-based PBT and polycarbonate, which have been used mainly in Europe by top car models of BMW and Mercedes.

Polyurethane is also used in bumpers where flexibility has the advantage of avoiding deformation. For example, a bumper which is made of polyurethane will roll back into its initial shape after small shock or collision where the speed is usually less than 5 km/h. It is very convenient and avoids costly repair.

For Nissan, they developed an integrated lightweight bumper system for their vehicle using higher modulus polypropylene. The usage of this material precluded the need for the steel reinforcement that up until then was necessary for the polypropylene bumper. In order to obtain the required material properties which is high in modulus and impact strength, an advanced compounding technology was applied to improve the existing mineral filled polypropylene bumper material. The higher modulus was achieved by advanced in compounding technologies which minimized the filler function and achieved in higher dispersion level for higher loading for fine particulate filler. Impact strength was increased by improving the interfacial strength between the polypropylene and elastomers particles by developing an alloy at the surface. This was obtained by optimization of the molecular structure of both components.

Basically, the most important mechanical properties of a car bumper are strength and toughness as well. Toughness is a mechanical term that is used in several contexts. Loosely speaking, it is a measure of the ability of materials to absorb energy before it tends to fracture. Fracture toughness is a property indicative of a material’s resistance to fracture when a crack is present. For a material to be tough, it must display both high strength and ductility.

In conclusion, good bumper performance requires not only engagement with the test barrier but also strength sufficient to absorb the energy of a low speed collision.

1.4 Problem statement

Consumers have to pay high price for damaged parts that need to be replaced due to low speed collision. Luxury cars, for instance are expensive not only to purchase but also to repair. Modern front-end styling results in bumper designs that can either slide under the bumpers or vehicles they strike or that simply do not have enough room to absorb the energy of a low speed crash. The bars underneath bumper covers often are not up to absorbing the energy. The bars may not be big enough to provide much protection from damage or they may be too flimsy to absorb much energy. In this case an impact damper is required to facilitate the impact energy absorption process while at the same time reducing or in some cases, avoiding the unnecessary cost to repair the damaged bumper.

1.5 Objective

The main objective of the project is to determine energy absorption structure to absorb the impact energy during a low speed collision. Low speed collision is defined as within the range of 2.5 km/h to 4 km/h. In order to achieve the main objective, the analysis of stress distribution on the bumper due to the collision, would be set as the secondary objective.

1.6 Scope

In pursuit to achieve the objective of this project, the circular tube has been identified as the energy absorbing structure. Circular tubes are selected due to their elastic flexibility and ability to absorb energy. Circular tubes are placed in the gap between front bumper and front cross member. The dimension of the gap is found to be 150 mm. Therefore the diameter of the tube is set as 150 mm as well.

Mathematical model of the circular tube in terms of strain-energy, displacement and circumferential stress are developed. The circumferential or hoop stress is used to determine the maximum stress in the tube for any length and thickness. The circumferential stress is used as the selection criteria because contribution of shear stress in the circular tube is negligible. The thickness and length that produces stress lower than yield strength is selected. Based on this length and thickness, the strain energy is calculated and number of energy absorber is determined as well.

Finally the assembly of the bumper, front cross member and energy absorbers is analyzed using COSMOSWorks to gauge the effectiveness of the energy absorption mechanism.