UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF THERMOPLASTIC TOUGHENED HYBRID KENAF/GLASS FIBRE-REINFORCED EPOXY COMPOSITE FOR AUTOMOTIVE BUMPER BEAM

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By

MAJID DAVOODI MAKINEJAD

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

This study is dedicated to my kind wife, Mojgan, my son, Parsa, and my daughter Parmis. They have been my support, strength, and inspiration on my journey to achieving this degree.

Abstract of thesis presented to the senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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Chairman : **Mohd Sapuan Salit, PhD, PEng**

Faculty : **Engineering**

Bumper is one of the important safety components of the passenger car. It has to withstand the low-impact collision from the external objects without severe damages as well as absorb the significant impact load during crushing. The estimated annual car productions show 76 million vehicles until 2020, so the End of Life Vehicles (ELV), which is being driven by European Union regulations, enforced the car manufacturers to consider the environmental impact by shifting from synthetic materials to agro-based materials. Hybridization of natural fibres with glass fibres provides a method for mechanical property's improvement. Kenaf is extracted from the bast of the annual fast-growing plant named *Hibiscus cannabinus*, which is considerably grown in Malaysia. The research initially commenced by investigating the bumper beams in local and imported passenger cars in Malaysia to find geometry (overall dimension, thickness, longitudinal radius), material (type, estimated ingredient, estimated production method) and energy damping system (five damping mechanism). Consequently, the hybrid kenaf/glass epoxy as composite and modified sheet moulding compound (SMC) as manufacturing method is selected. After some

preliminary trial, it is concluded that material makes from 2 plies of kenaf and 3 plies of fibre glass, with fibre orientation (0, 90, 0, 90, 0). The fibres are fixed onto a thin steel frame, while they were stretched by a fixture. Epoxy and hardener with 100:14 w/t % sprayed on them and pressed into a controlled heat and pressure sealed steel mould. The results indicated that, apart from impact property, other mechanical properties such as tensile strength, Young's modulus, flexural strength and flexural modulus are comparable with glass mat thermoplastic (GMT). Since the impact property did not fulfill the common bumper beam material GMT, in second step, 5 w/t % polybutylene terephthalate (PBT) was used to improve the epoxy toughness and impact properties with a low thermo-mechanical drawback. The impact property was improved by only 54%, which was lower than the GMT. The third part of the research concentrated on improving the geometrical structure by selecting the best bumper beam concept to fulfill the safety parameters of the pre-defined product design specification (PDS). The mechanical properties of the developed hybrid composite material are considered for whole bumper beam concepts with the same frontal curvature, thickness, and overall dimensions. The low- speed impact test was simulated under the same condition in ABAQUS V16R9 software. Six weighted criteria consisted of deflection, strain energy, mass, cost, easy manufacturing, and the possibility of the ribs were analyzed to form an evaluation matrix. TOPSIS method was employed to select the best concept. It was concluded that double hat profile (DHP) is a more suitable concept for bumper beam. Finally, the low impact test was carried out to the selected bumper beam concept (DHP) when the vertical strength ribs were added. The results showed that the deflection decreases by 11% and the strain energy increased by 11.3% compare with unribbed bumper beam. Overall, it was concluded that the mechanical properties of the PBT toughened

hybrid kenaf/glass epoxy composite under controlled SMC manufacturing method can enhance the structural strength and could be potentially employed in the automotive structural component.

Abstrak tesis dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN KOMPOSIT EPOKSI BERTETULANG-GENTIAN KENAF/KACA HIBRID DIPERKUAT TERMOPLASTIK UNTUK RASUK BAMPER AUTOMOTIF

Oleh

MAJID DAVOODI MAKINEJAD

Januari 2012

Pengerusi : **Mohd Sapuan Salit, PhD, PEng**

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Bamper adalah salah satu komponen keselamatan penting bagi kereta. Ia perlu menahan pelanggaran hentaman rendah daripada objek luar tanpa kerosakan teruk dan juga menyerap bebanan hentaman yang signifikan semasa penghancuran. Oleh kerana anggaran pengeluaran kereta tahunan menunjukkan 76 juta kenderaan sehingga tahun 2020; Kenderaan Akhir Hayat (ELV), yang didorong oleh peraturan Kesatuan Eropah, menguatkuasa pengilang mempertimbangkan impak persekitaran and peralihan daripada bahan sintetik kepada bahan asas tani. Penghibridan gentian asli dengan gentian kaca memberikan satu kaedah untuk penambahbaikan sifat mekanikal, Kenaf diekstrak daripada kulit bagi pokok yang cepat membesar tahunan bernama Hibiscus cannabinus, yang ditanam di Malaysia. Penyelidikan ini pada mulanya tertumpu kepada kajian rusuk bumper dalam kereta tempatan dan import di Malaysia bagi mendapatkan geometri (dimensi keseluruhan, ketebalan, jejari longitud) bahan (jenis, rumuan anggaran, kaedah penbuatan anggaran dan sistem redaman tenaga (lima mekanisme redaman. Seterusaya, epoksi kenaf/kaca hibrid

sebagai komposit dan sebatian pengacuan keping (SMC) yang diubahsuai sebagai kaedch pembuatan telah dipilih. Selepas beberapa ujian awal, bahan yang dibuat daripada 2 lapis kenaf dan 3 lapis gentian kaca, dengan penghalaan (0,90,0,90,0) telah dipilih. Gentian dipasangkan ke kerangka keluli nipis, di mana bahan ini telah diregangkan oleh satu lekapan. Epoksi dan pengeras dengan nisbah 100:14 mengikut peratusan berat telah disembur ke atas bahan tersebut dan ditekan ke dalam sebuah acuan keluli kedap yang dikawal haba dan tekanannya. Keputusan menunjukkan, selain daripada sifat hentaman, sifat mekanikal yang lain seperti kekuatan alah, modulus Young, kekuatan lenturan dan modulus lenturan adalah setanding dengan termoplastik tikar kaca (GMT). Disebabkan ketidakupayaan memenuhi sifat hentaman bagi bahan rasuk bamper GMT, berikutnya, penguatan polibutilena tereftalat (PBT) sebanyak 5 % mengikut berat telah digunakan bagi meningkatkan sifat keliatan dan hentaman epoksi dengan kelemahan termo-mekanikal yang rendah. Sifat hentaman telah meningkat sebanyak 54%, yang mana lebih rendah daripada GMT. Bahagian ketiga penyelidikan memberi tumpuan kepada pemilihan geometri yang terbaik bagi konsep rasuk bamper bagi memenuhi parameter keselamatan spesifikasi reka bentuk produk (PDS) yang telah ditetapkan. Sifat mekanikal bagi bahan komposit hibrid yang dibangunkan telah dipertimbangkan untuk pelbagai konsep rasuk bamper dengan kelengkungan frontal, ketebalan dan dimensi keseluruhan yang sama. Ujian hentaman kelajuan rendah telah disimulasi di bawah keadaan yang sama dalam perisian ABAQUS V16R9. Enam kriteria berpemberat terdiri daripada pesongan, tenaga terikan, jisim, kos, pembuatan mudah, dan kemungkinan untuk memasukkan rusuk telah dianalisis bagi membentuk satu matrik penilaian. Kaedah TOPSIS telah digunakan bagi memilih konsep yang terbaik. Kesimpulannya, konsep profil topi duaan (DHP) dengan model bahan yang ditakrif

adalah lebih sesuai untuk rasuk bamper. Akhirnya ujian hentaman rendah telah dijalankan ke atas konsep rasuk bumper terpilih (DHP) setelah rusuk kekuatan tegak ditambah. Keputusan menunjukkan bahawa pesongan berkurangan sebanyak 11% dan tenaga terikan bertambah sebanyak 11.3% berbanding dengan rasuk bumper tanpa rusuk. Secara keseluruhannya, dapat dibuat kesimpulan bahawa sifat mekanikal komposit kaedah pembuatan SMC terkawal boleh meningkatkan kekuatan struktur automotif..

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LIST OF NOTATIONS AND ABBREVIATIONS

a	Acceleration
ACEA	Association des Constructeurs Europèens d'Automobile
AISI	American Iron and Steel Institute
ASTM	American Society for Testing and Materials
BMC	Bulk Moulding Compound
C	Damping Coefficient
CAE	Computer Aided Engineering
CIB	Crash Integrated Bumper
CMVSR	Canadian Motor Vehicle Safety Regulation
CNT	Carbon Nano Tubes
d	Distance
DHP	Double Hat Profile
d_f	Fibre damage
d_m	Matrix damage
d_s	Shear damage
E	Young's modulus
E_c	Kinetic energy
ECE	Economic Commission for Europe
ELV	End of Life Vehicles
EPDM	Ethylene Propylene Diene Monomer
FEA	Finite Element Analysis
F_{mt}	Failure in matrix tension
FRC	Fibre Reinforced Composites
g	Gravitational acceleration
GI_c	Fracture Toughness Energy
GMT	Glass Mat Thermoplastic
h	Composite thickness
HD-SRIM	High Density Structural Reaction Injection Molding

HTPC	Hybrid Thermoplastic Composites Beam
k	Spring Coefficient
LD-SRIM	Low Density Structural Reaction Injection Molding
NFC	Natural Fibre Composite
NHTSA	National Highway Traffic Safety Administration
NMT	Natural Fibre Mat Thermoplastic
OEM	Original Equipment Manufacturer
σ	True stress
σ°	Effective stress
PBT	Polybutylene Terephthalate
PC	Polycarbonate
Pcr	Critical force
PDS	Product Design Specification
PP	Polypropylene
RRIM	Reinforced Reaction Injection Moulding
RTM	Resin Transfer Moulding
S^{L}	Longitudinal shear strength
SMC	Sheet Moulding Compound
SME	Society of Manufacturing Engineers
SRIM	Structural Reaction Injection Molding
TSF	Thick Sheet Forming
V	Velocity
ν	Poisson's ratio
WBCSD	World Business Council for Sustainable Development
Y^{T}	Traverse tensile strength

CHAPTER 1

INTRODUCTION

1.1 Background

Automotive productions have grown in recent century while environmental, economic and technological reasons enforced car manufacturer and engineers to look for new materials which will decrease cost, fuel consumption, and increase performance while, maintaining their competitive edge and profit margin (Hess, et al., 1996; Mair., 2000). The energy consumption and emissions was decreased by the automotive weight reduction. Moreover, new regulation "End-of-Life-Vehicle-Directive" led car manufacturers to substitute renewable natural resources, which produce green product, reduce CO_2 emissions as well as save the conventional fossil resources (Mohanty, et al., 2002). Expectations were that about 70% of the energy consumption and CO_2 emissions were caused by the car (ACEA, 2002). Besides, if 25% weight of the vehicles are reduced, it is capable of saving up to 250 million barrels of crude oil (Mair, 2000).

Scientists and technologists recently concerned about natural fibres due to low density, cost, low production energy requirement, lower tool wearing rate, good formability, suitable acoustic, renewability and thermal insulating as well as no splintering functions. Therefore, the application of bio-composite's is rapidly growing in past two decades (Wambua, 2003), but low mechanical properties limit their use in automotive non-structural and semi-structural components. Natural fibre hybridization with glass is capable of enhancing the strength of the composite and

impact on different stress modes which depend on the construction and design (Ray and Rout 2005). The low-impact property of composite materials can be enhanced by incorporation of discrete layers of tough resin (interleaving), introduction of z-directional fibre (stitching) and addition of whiskers or short fibres to the inter-laminar zone (supplementary reinforcement). Moreover, thermoplastic (PBT) epoxy toughening improvement may assist to overcome the desired deficiency of composite material with structure-less morphology under SMC controlled manufacturing condition.

Studies on the comparison between metal bumper beam with impact analysis of common bumper beam, metal, sheet moulding compound (SMC), glass mat thermoplastic (GMT) and the effect of design parameters in energy absorption have been reported (Hosseinzadeh, et al., 2005; Marzbanrad, et al., 2009). Moreover, improvement of the epoxy toughness was used in synthetic composite toughness improvement. In the present study is aimed at developing a hybrid kenaf/glass epoxy composite and design parameters, which can be compared with GMT. In addition, the toughness improvement of the hybrid bio-composite epoxy, with kenaf temperature limitation, was also investigated. The thermoset matrix composites are not as easy recyclable as a thermoplastic composite, but the demand for improved recycling concepts of thermoset material can substitute it by thermoplastic matrix (Bruijn, 2000).

1.2 Problem statement

Automobile productions have increased in the last 20 years. According to estimation of the Organization for Economic Cooperation and Development (OECD), the total number of vehicles was expected to grow by 32% from 1997 to 2020. The concerns of End of Life Vehicle Recycling, which was driven by European Union regulations, have forced car manufacturers to look for new materials (natural resources) for their upcoming product with 95% (biodegradable) and 85% (recyclable) until 2015.

Furthermore, the low density of natural fibers compare with synthetic fibers reduces the car weight between10% to 30% and will reduce fuel consumption. It is estimated a weight reduction up to 25% in each vehicle cause an equal reduction in carbon dioxide (CO_2) discharged and saving 250 million barrels of crude oil (Mair, 2000). So, car manufacturers focused on natural fibre composite in place of traditionally used steels.

Limitation of the world's petrol based resource as a main raw material for car manufacturers and possibility of escalation of price rate in the future, is another major factor to utilize bio-composites for price and weight reduction of vehicles. Moreover, abundant resources of natural fibres in many nations as well as the low cost encouraged manufacturers to use more natural resources in their future products.

Occupational health benefits compared with petrol based material during production. No off-gassing of toxic compounds (in contrast to phenol resin bonded wood and

recycled cotton fibre parts) is another issue of production of polymer based material compared with natural fibres (Claudette, 2006).

Kenaf reported a high modulus 40-53 GPa due to rich cellulose content (about 53-57 wt. %) (Akil, et al., 2011). It has a very high capability to absorb carbon dioxide about 3 – 9 times more than average and generate extra oxygen. It herbaceous annual plant can grow to 3-4 m in less than in 5 to 6 months in many regions with less water than traditional crops and have a good performance to price ratio (Nishimura, 2006). Low mechanical properties of the natural fibers confine their application to automotive non-structural and semi structural components. The impact properties of the bio-composite material can be enhanced by fibre (hybridization), matrix (toughened epoxy) and manufacturing (SMC) improvements. Hybridization of natural fibre with glass fibre (Samal, et al., 2009) (Mehta, et al., 2005) and Z-direction reinforcement method can improve the impact property, delamination resistance and fracture toughness (Nashed, et al., 2011), but Z-direction reinforcement needs special equipment for stitching the fibre in the laminate (Tong, et al., 2002). The main deficiency of epoxy (impact property) can be significantly increase by toughening (double phase morphology) and flexibilisation (single phase morphology) method. Toughening offers impact enhancement without deterioration of thermo mechanical properties. Thermoplastic toughening presents lower degradation of epoxy stiffness and modulus compare with liquid rubber toughening and rigid particle toughening. Low molecular weight and unreactive thermoplastics, polyether sulfone, (PES), did not increase fracture toughness significantly (C. B. Bucknall and Partridge, 1983). Crystalline thermoplastics (PBT) present significant epoxy toughening improvement with elevated temperature. (Nichols and Robertson,

1994) found 5 wt. % PBT was able to increase the fracture energy (GIc) of a brittle epoxy from180 to 2000 J/m2 with proper control of morphology.

This study focused on improving the mechanical properties of kenaf fibre by hybridization with glass fibre and improving the impact property of epoxy by thermoplastic (PBT) toughening as well as using modified SMC manufacturing method. The possibility of utilization the developed material for automotive structural components (bumper beam) is investigated by simulating the low impact test.

1.3 Research objectives

The general objective of this research is to explore the possibilities of using toughened hybrid kenaf/glass epoxy composite in automotive structural components and comply with the low speed impact test, which is defined in product design specification (PDS). The specific objectives of this study can be summarized as follows:

- To develop a hybrid kenaf/glass epoxy composite material for automotive structural components (bumper beam).
- To improve the impact properties (toughness) of developed hybrid kenaf/glass epoxy composite by thermoplastic toughening (PBT).
- To improve the geometrical property of the bumper beam by selecting the best concept and adding strengthen ribs and verify it by finite element method based on bumper safety standard.

1.4 Significance of study

The significance of this study is on the use of hybrid kenaf/glass fibre reinforced composites for use in automotive structural components, instead of typical bumper beam material, glass mat thermoplastic (GMT). Kenaf has a process limitation temperature. Investigation was performed to improve the epoxy toughness by the use of 5 w/t% polybutylene terephthalate (PBT) in developed hybrid material by structure-less morphology to produce the hybrid sheet under controlled SMC manufacturing condition. Moreover, the effect of geometrical parameters in the desired application was analysed using ABAQUS FEA software.

1.5 Scope and limitation of study

This study involves improvement of the main mechanical properties of the hybrid bio-composite material for use in automotive structural components by hybrid kenaf/glass fibre. The product design specification was organized based on the available data, and the low-impact test was simulated by ABAQUS V16R9 software in order to comply with the safety mode of defined product design specification (PDS). There are various parameters for structural improvement (cross-section, thickness, fixing method, frontal curvature and strength ribs).

This study focused on concept selection within six studied parameters (deflection, strain energy, product weight, adding rib possibility, easy manufacturing and material cost). The real low speed impact test comprises all bumper components, which is not possible for the author to model all components. The simulated test was conducted in assembled bumper beam and energy absorbers as main bumper safety

components. The research, did not develop a real manufacturing method rather, the available processes were modified in order to enhance a better quality.

1.6 Thesis layout

This research is divided into three steps.

The first part emphasized on developing a hybrid composite, manufacturing method, and fibre orientation. The second part was on improving the impact property with epoxy thermoplastic toughening. The third stage evaluates the geometrical improvement that selects the best concept of a car bumper beam, which complies with the product design specification (PDS) and finally is concerned with low impact test analysis for the selected geometry and possibility of structural improvement to increase the impact strength.

This thesis is divided into nine chapters; following this chapter is the literature review, which reviews related publications to the bumper components, composite material, hybrid material, and analysis method. Chapter 3 comprised of systematic approach and methodology used in the research.

Chapters 4 to 8 are the published journal articles during this study, which form the major contribution of this research. Chapter 4 presents the first article entitled "Mechanical properties of hybrid kenaf/glass reinforced epoxy composite for car passenger bumper beam". The first article reports on the developed hybrid material and its mechanical properties compared with GMT. Chapter 5 presents the second

article entitled "Effect of polybutylene terephthalate (PBT) on impact property improvement of hybrid kenaf/glass epoxy composite". This article discusses on the epoxy toughness improvement by using 5% PBT. It presents the impact property enhancement in comparison to the first batch and GMT. Chapter 6 presents the third article entitled "Concepts selection of car bumper beam with developed hybrid bio-composite material". This article investigated eight different bumper beam concepts with six criteria. All concepts were subjected to the low impact test to determine the deflection and energy absorption. The TOPSIS method has been used to come up with the best concept. The double hat profile has been appointed as the best concept. Chapter 7 present the forth paper "effect of the strengthen ribs in hybrid toughened kenaf/glass epoxy composite bumper beam". Finally, conclusions and recommendations for future work are presented in chapter 8.

REFERENCES

Abrate, S. (1998). *Impact on Composite Structures*. New York: Cambridge University Press.

ACEA. (2002). ACEA Programme on Emissions of Fine Particles from Passenger Cars. Retrieved July 2008 www.acea.be.

Aclaryn Plastics. (2009). The Injection Molding Process. Retrieved Dec 2009, from Aclaryn Plastics http://www.aclaryn.com/injection.html

Adriani, O., Aguilar-Benitez, M., Ahlen, S., Alcaraz, J., Aloisio, A., Alverson, G., et al. (1992). High mass photon pairs in l+ l-gammagamma events at LEP. *Physics Letters B,* 295, 337-346.

Advani, S. G., and Sozer, E. M. (2010). *Process Modeling in Composites Manufacturing*. New York: Taylor and Francis.

Agarwal, R., Saxena, N., Sharma, K. B., Thomas, S., and Pothan, L. A. (2006). Thermal conduction and diffusion through polyester composites. *Indian Journal of Pure and Applied Physics,* 44(10), 746.

AISI. (2006). Steel Bumper Systems for Passenger Cars and Light Trucks (Vol. 3). Southfield: American Iron and Steel Institute.

Akil, H., Omar, M., Mazuki, A., Safiee, S., Ishak, Z., and Abu Bakar, A. (2011). Kenaf fiber reinforced composites: A review. *Materials & Design*.

Al-Ashaab, A., Rodriguez, K., Molina, A., Cardenas, M., Aca, J., Saeed, M., et al. (2003). Internet-based collaborative design for an injection-moulding system. *Concurrent Engineering,* 11(4), 289.

Alghamdi, A. (2000). Smart frictional impact energy absorber. *International Journal of Crashworthiness,* 5(2), 169-178.

Alghamdi, A. (2001). Collapsible impact energy absorbers: an overview. *Thin-Walled Structures,* 39(2), 189-213.

Alvarez, V., Vazquez, A., and Bernal, C. (2005). Fracture behavior of sisal fiber - reinforced starch - based composites. *Polymer Composites,* 26(3), 316-323.

American Society for Testing and Materials. (2004). Standard test methods for determining the Izod pendulum impact resistance of plastics (Vol. D256-04). Pennsylvania: ASTM.

Ashby, M., Shercliff, H., and Cebon, D. (2007). *Materials Engineering, Science,Processing and Design* (Vol. 1). Oxford: Elsevier Ltd.

Ashby, M. F., and Johnson, K. (2002). *Materials and Design: the Art and Science of Material Selection in Product Design*. Woburn: Butterworth-Heinemann.

Ashby., M., and Bréchet, Y. (2003). Designing hybrid materials. *Acta Materialia,* 51(19), 5801-5821.

Ashby., M. F. (2005). *Materials Selection in Mechanical Design*. Oxford: Butterworth-Heinemann.

B. John. (2004). HYBRIDMAT 2: Strategies in the joining of hybrid materials in automotive structures.

Baccouche, R., Mahmood, H., Madasamy, C., and Wagner, D. (2007). Lightweight bumper for automobiles.

Becky Joitke. (2006). High Volume Processing of Composites. Retrieved from http://www1.eere.energy.gov/vehiclesandfuels/pdfs/alm_06/4c_joitke.pdf

Bedard, M., Guyatt, G. H., Stones, M. J., and Hirdes, J. P. (2002). The independent contribution of driver, crash, and vehicle characteristics to driver fatalities. *Accident Analysis & Prevention,* 34(6), 717-727.

Benevolenski, O., Karger-Kocsis, J., and Mieck, K. (2001). Reubmann,"Instrumented perforation impact response of polypropylene composites with hybrid reinforcement flax/glass and flax/cellulose fibers". *Journal of Thermoplastic Composite Materials,* 13(6), 381-496.

Berthelot, J. M. (1999). *Composite Materials: Mechanical Behavior and Structural Analysis*. New York Springer

Bhattacharyya, D. (1997). *Composite Sheet Forming*. New York Elsevier

Bledzki, A. K., Faruk, O., and Sperber, V. E. (2006). Cars from bio-fibres. *Macromolecular Material Engineering,* 291, 449–457.

Bledzki, A. K., Sperber, V. E., and Faruk, O. (2002). *Natural and wood fibre reinforcement in polymers*. Shropshire: Rapra Technology Ltd.

Boehler, J. P. (2005). *Yielding, Damage, and Failure of Anisotropic Solids*. New York: John Wiley & Sons.

Borst, R., and Sadowski, T. (2008). *Lecture Notes on Composite Materials: Current Topics and Achievements*. Eindhoven: Springer.

Brosius, D. (2006). Natural fiber composites slowly take root. *Composites Technology*, 32-37.

Bruijn, d. J. C. M. (2000). Natural Fibre Mat Thermoplastic Products from a Processor's Point of View. *Journal of Applied Composite Material,* 7, 415–420.

Brydson, J. A. (1999). *Plastics Materials*. New Delhi: Butterworth-Heinemann.

Bucknall, C., and Gilbert, A. (1989). Toughening tetrafunctional epoxy resins using polyetherimide. *Polymer,* 30(2), 213-217.

Bucknall, C. B., and Partridge, I. K. (1983). Phase separation in epoxy resins containing polyethersulphone. *Polymer,* 24(5), 639-644.

Calamari, T. A., Tao, W., and Goynes, W. R. (1997). A preliminary study of kenaf fiber bundles and their composite cells. *Tappi Journal,* 80(8), 149-153.

Cars, P. (1989). US Departement of Transportation National Highway Traffic Safety Administration.

Chem, D., and Riedel, U. *Natural fibre Reinforced Biopolymers as Construction Materials – New Discoveries.* Paper presented at the 2nd International Wood and Natural Fibre Composites Symposium,Kassel/Germany.28-29 June 1999

Chen, C. (2000). Extensions of the TOPSIS for group decision-making under fuzzy environment. *Fuzzy sets and systems,* 114(1), 1-9.

Cheon, S., Lee, D., and Jeong, K. (1997). Composite side-door impact beams for passenger cars. *Composite Structures,* 38(1-4), 229-239.

Cheon., S. S., Choi, J. H., and Lee, D. G. (1995). Development of the composite bumper beam for passenger cars. *Composite Structures,* 32(1-4), 491-499.

Cicero, J. A., Dorgan, J. R., Dec, S. F., and Knauss, D. M. (2002). Phosphite stabilization effects on two-step melt-spun fibers of polylactide. *Polymer Degradation and Stability,* 78(1), 95-105.

Clark, R., and Ansell, M. P. (1986). Jute and glass fibre hybrid laminates. *Journal of Materials Science,* 21(1), 269-276.

Claudette, J. (2006). Automotive Plastics Report Card. Retrieved Dec 2010 http://www.ecocenter.org/healthy-stuff/automotive-plastics-report-card

CSM Worldwide. (2005). Light Vehicle Forecast. Retrieved July 2008 http://www.marklines.com/en/report/rep379_200506?search=true

Cunliffe, A. M., Jones, N., and Williams, P. T. (2003). Recycling of fibre-reinforced polymeric waste by pyrolysis: thermo-gravimetric and bench-scale investigations. *Journal of Analytical and Applied Pyrolysis,* 70, 315-338.

Cyclics Corporation. (2008). Product imformation. In C. Corporation (Ed.). New York.

Dassault System. (2008). Analysis of Composite Materials with Abaqus.

Davies, G. (2003). *Materials for Automobile Bodies.* Oxford: Elsevier.

Davis, B. A. (2003). *Compression Molding.* Cincinnati: Hanser Publishers.

Davoodi, M., Sapuan, S., Ahmad, D., Aidy, A., Khalina, A., and Jonoobi, M. (2011). Concept Selection of Car Bumper Beam with Developed Hybrid Bio-Composite Material. *Materials & Design,* 32, 4857–4865.

Davoodi, M. M., Sapuan, S. M., Ahmad, D., Aidy, A., and Khalina, A. (2008). A Review on Natural Fiber Composites in Automotive Industry. S. M. Sapuan (Ed.), *Research in natural fiber reiforced polymer composite* Selangor: UPM press.

Davoodi, M. M., Sapuan, S. M., Ahmad, D., Aidy, A., Khalina, A., and Jonoobi, M. (2012). Effect of polybutylene terephthalate (PBT) on impact property improvement of hybrid kenaf/glass epoxy composite. *Materials Letters,* 67(1), 5-7.

Davoodi, M. M., Sapuan, S. M., and Yunus, R. (2008). Conceptual design of a polymer composite automotive bumper energy absorber. *Materials & Design,* 29, 1447–1452.

Davoodi, M. M., Sapuan, S. M., and Yunus, R. (2008). Development of fiber reinforced epoxy composite energy absorber for automotive bumper system. *Journal of Polymer Materials* 25 (1), 15-21.

Dekker, M. (2003). *Handbook of Polypropylene and Polypropylene Composites*. New York: Marcel Dekker.

Dieter, G. E. (2000). *Engineering Design: A Materials and Processing Approach*. New York: McGraw-Hill.

Dieu, T. V., Liem, N. T., Mai, T. T., and Tung, N. H. (2004). Study on Fabrication of BMC Laminates Based on Unsaturated Polyester Resin Reinforced by Hybrid Bamboo/Glass Fibers. *JSME International Journal Series A,* 47(4), 570-573.

Donald E. Hudgin. (2006). *Plastics Technology Handbook*: Taylor & Francis Group.

Drozda, T., Mitchell, P. E., Wick, C., and Engineers, S. o. M. (1998). *Tool and Manufacturing Engineers Handbook: Material and part handling in manufacturing*. New York: Society of Manufacturing Engineers.

Du, Y., Zhang, J., Toghiani, H., Lacy, T., Xue, Y., Horstemeyer, M., et al. (2010). Kenaf Bast Fiber Bundle-Reinforced Unsaturated Polyester Composites. I: Processing Techniques for High Kenaf Fiber Loading. *Forest Products Journal,* 60(3), 289-295.

ECE. (1980). Uniform provisions concerning the approval of vehicles with regard to front and rear protective devices (Bumper, etc) Retrieved Dec 10, 2010, from http://live.unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/r042e.pdf

Echaabi, J., Trochu, F., and Gauvin, R. (1996). Review of failure criteria of fibrous composite materials. *Polymer Composites,* 17(6), 786-798.

Eichhorn, S., and Young, R. (2004). Composite micromechanics of hemp fibres and epoxy resin microdroplets. *Composites Science and Technology,* 64(5), 767-772.

Esbjerg, A. (2003). Course in nonlinear FEM. Retrieved from http://people.civil.aau.dk/~ask/ansys/FEM-nonlinear-introduction.pdf

Farag, M. (2008). Quantitative methods of materials substitution: Application to automotive components. *Materials and Design,* 29(2), 374-380.

Faruk, O. (2006). Cars from jute and other biofibers. Michigan: Natural Resources Building Michigan State University.

Fung, R., Chen, Y., and Tang, J. (2007). A quality-engineering-based approach for conceptual product design. *The International Journal of Advanced Manufacturing Technology,* 32(11), 1064-1073.

Gassan, J., and Bledzki, A. (2000). Possibilities to Improve the Properties of Natural Fiber Reinforced Plastics by Fiber Modification–Jute Polypropylene Composites–. *Applied Composite Materials,* 7(5), 373-385.

Gassan, J., and Bledzki, A. K. (1999). Possibilities for improving the mechanical properties of jute/epoxy composites by alkali treatment of fibres. *Composites Science and Technology,* 59(9), 1303-1309.

Goldhawk, M., and Wesolowski, M. (2003). 2003-01-0209 Considerations in Material, Part, and Process Design for Downgauged RRIM Applications. *SAE SP*, 21-32.

Gosse, J. H. (2001). Strain Invariant failure criteria for polymer in composite materials,A collection of technical papers: AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference (Vol. Vol 1, pp. 45-55): American Institute of Aeronautics and Astronautics.

Guido Kickelbick. (2007). Hybrid Materials: Synthesis, Characterization, and Applications. Weinheim: Wiley-VCH.

Gupta, S. *Using CAE to evaluate structural foam alternatives in B-pillar and bumper designs*. 2001.

Hambali, A., Sapuan, S., Ismail, N., and Nukman, Y. (2009). Application of analytical hierarchy process in the design concept selection of automotive composite bumper beam during the conceptual design stage. *Scientific Research and Essays,* 4(4), 198-211.

Haque, E., Bassett, W., and Lewis, T. (2001).

Harper, C. A. (2002). *Handbook of Plastics, Elastomers, and Composites*. New York: McGraw-Hill Professional.

Harper, C. A. (2006). *Handbook of plastic processes*: Wiley-Interscience.

Harrigan, J., Reid, S., Tan, P., and Yella Reddy, T. (2005). High rate crushing of wood along the grain. *International Journal of Mechanical Sciences,* 47(4-5), 521-544.

Hartemann, F., Thomas, C., Foret-Bruno, J., Henry, C., Fayon, A., and Tarriere, C. (1976). Occupant protection in lateral impacts: Society of Automotive Engineers, 400 Commonwealth Dr, Warrendale, PA, 15096, USA.

Hashin, Z. (1980). Failure criteria for unidirectional fiber composites. *Journal of applied mechanics,* 47, 329.

Helps, I. G. (2001). *Plastics in European Cars 2000-2008: A Rapra Industry Analysis Report*. Sheropshire: Smithers Rapra Publishing.

Henkhaus, K. *Overview of research on composite material impact behavior.* Proceedings of the Engineering Mechanics, Seattle. 2003.

Hess, J. D., Chu, W., and Gerstner, E. (1996). Controlling product returns in direct marketing. *Marketing Letters,* 7(4), 307-317.

Hibbitt, K., Karlsson, B., and Sorensen, E. (2002). ABAQUS Theory Manual

Holbery, J., Houston, D. (2006). Natural-Fiber-Reinforced Polymer Composites in Automotive applications *JOM Journal of the Minerals, Metals and Materials Society,* 58(11), 80-86. doi: 10.1007/s11837-006-0234-2

Hosseinzadeh, R., Shokrieh, M., and Lessard, L. (2005). Parametric study of automotive composite bumper beams subjected to low-velocity impacts. *Composite Structures,* 68(4), 419-427.

Hoyle, C., and Chen, W. (2009). Product attribute function deployment (PAFD) for decision-based conceptual design. *Engineering Management, IEEE Transactions on,* 56(2), 271-284.

Hsiao, S. (1998). Fuzzy logic based decision model for product design. *International Journal of Industrial Ergonomics,* 21(2), 103-116.

Hsu , W., and Woon , I. (1998). Current research in the conceptual design of mechanical products. *Computer-Aided Design,* 30, 377-389.

Hsu, W., and Woon, I. (1998). Current research in the conceptual design of mechanical products. *Computer-Aided Design,* 30(5), 377-389.

Huda, M. S., Drzal, L. T., Mohanty, A. K., and Misra, M. (2008). Effect of fiber surface-treatments on the properties of laminated biocomposites from poly (lactic acid)(PLA) and kenaf fibers. *Composites Science and Technology,* 68(2), 424-432.

Hull, D., and Clyne, T. W. (1996). *An introduction to composite materials*: Cambridge University Press.

Hull., D., and Clyne, T. (1996). *An Introduction to Composite Materials*. Cambridge: Cambridge University Press.

Huthwaite, B. *Manufacturing competitiveness and quality by design.* Proceedings of the 4th International Conference Product Design for Manufacture and assembly, Stockholm,Sweden.5-6 June 1989.

Hwang., C., and Yoon, K. (1981). Multiple Attribute Decision Making: Methods and Applications: A State-of-the-Art Survey (Vol. 13). New York: Springer.

Jacob, G., Fellers, J., Simunovic, S., and Starbuck, J. (2002). Energy absorption in polymer composites for automotive crashworthiness. *Journal of Composite Materials,* 36(7), 813.

Jahn, A., Schroder, M., Futing, M., Schenzel, K., and Diepenbrock, W. (2002). Characterization of alkali treated flax fibres by means of FT Raman spectroscopy and environmental scanning electron microscopy. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy,* 58(10), 2271-2279.

James, E. d. (2007). The Future of Composites in the Automotive Industry. Retrieved July 2008, from Ford Innovation and Research Center http://www.eng.wayne.edu/user_files/56/ME7720GuestLectureW07_deVries.pdf

John , K., and Naidu, S. V. (2004). Sisal fiber/glass fiber hybrid composites: the impact and compressive properties. *Journal of reinforced plastics and composites,* 23(12), 1253.

John, M. J., and Thomas, S. (2008). Biofibres and biocomposites. *Carbohydrate Polymers,* 71(3), 343-364.

John., B. (2004). HYBRIDMAT 2: Strategies in the joining of hybrid materials in automotive structures (pp. 23).

Joseph, K., L.H.C. Mattoso, R.D. Toledo, S. Thomas, L.H. de Carvalho, L. Pothen, et al. (2000). Natural fiber reinforced thermoplastic composites. E. Frollini, A. L. Leão andL. H. C. Mattoso (Eds.), *Natural Polymers and Agrofibers Composites* (pp. 159-201). Sãn Carlos, Brazil: Embrapa.

Justin, F. (2001). Glass Mat Thermoplastic Composites. Retrieved July 2008, from Materials Information Service http://www.azom.com/article.aspx?ArticleID=318

Kalaprasad, G., Francis, B., Thomas, S., Kumar, C. R., Pavithran, C., and Groeninckx, G. (2004). Effect of fibre length and chemical modifications on the tensile properties of intimately mixed short sisal/glass hybrid fibre reinforced low density polyethylene composites. *Polymer international,* 53(11), 1624-1638.

Karus, M., and Kaup, M. (2002). Natural fibres in the European automotive industry. *J. Int. Hemp Assoc,* 7(1), 119-131.

Keinonen, T., and Takala, R. (2006). *Product Concept Design: A Review of the Conceptual Design of Products in Industry*. New York: Springer

Khan, M., Hinrichsen, G., and Drzal, L. (2001). Influence of novel coupling agents on mechanical properties of jute reinforced polypropylene composite. *Journal of Materials Science Letters,* 20(18), 1711-1713.

Khan., M. A., Ganster, J., and Fink, H. P. (2009). Hybrid composites of jute and man-made cellulose fibers with polypropylene by injection moulding. *Composites Part A: Applied Science and Manufacturing,* 40(6-7), 846-851.

Khashaba, U. (2004). In-plane shear properties of cross-ply composite laminates with different off-axis angles. *Composite Structures,* 65(2), 167-177.

Kickelbick, G. (2007). *Hybrid Materials: Synthesis, Characterization, and Applications*. Vienna: Wiley - VCH.

Kim , J., Nichols, M. E., and Robertson, R. E. (1994). The annealing and thermal analysis of poly (butylene terephthalate). *Journal of Polymer Science Part B: Polymer Physics,* 32(5), 887-899.

Kim, J., and Robertson, R. (1992). Toughening of thermoset polymers by rigid crystalline particles. *Journal of Materials Science,* 27(1), 161-174.

Kim, S., Jo, W. H., Kim, J., Lim, S. H., and Choe, C. R. (1999). The effect of crystalline morphology of poly (butylene terephthalate) phases on toughening of poly (butylene terephthalate)/epoxy blends. *Journal of Materials Science,* 34(1), 161-168.

Kim., K., and Won, S. (2008). Effect of structural variables on automotive body bumper impact beam. *International Journal of Automotive Technology,* 9(6), 713-717.

Kroll, E., Condoor, S. S., and Jansson, D. G. (2001). *Innovative Conceptual Design: Theory and Application of Parameter Analysis*. Cambridge: Cambridge University.

Lal, K. (1983). Low velocity transverse impact behavior of 8-ply, graphite-epoxy laminates. *Journal of reinforced plastics and composites,* 2(4), 216.

Lavery, M. (2002). Sealants in the automotive industry. International *International Journal of Adhesion & Adhesives,* 22 (6), 443–445.

Lawrence, G., Hardy, B., Carroll, J., Donaldson, W., Visviskis, C., and Peel, D. (2004). A study on the feasibility of measures relating to the protection of pedestrians and other vulnerable road users. *Transportation Research Library.*

Lee, D. G., and Suh, N. P. (2006). *Axiomatic Design and Fabrication of Composite Structures: Applications in Robots, Machine tools, and Automobiles*. New York: Oxford University Press.

Lee., B. J., McDonald, A. G., and James, B. (2001). Influence of fiber length on the mechanical properties of wood-fiber/polypropylene prepreg sheets. *Materials Research Innovations,* 4(2), 97-103.

Li, G., Zhou, R. G., Duan, L., and Chen, W. F. (1999). Multiobjective and multilevel optimization for steel frames. *Engineering Structures,* 21(6), 519-529.

Liu, W., Thayer, K., Misra, M., Drzal, L. T., and Mohanty, A. K. (2007). Processing and physical properties of native grass reinforced biocomposites. *Polymer Engineering & Science,* 47(7), 969-976.

Long, A. C. (2007). *Composites Forming Technologies*. Manchester: Woodhead.

Loo, Y. C., Chowdhury, S. H., and Fragomeni, S. (2002). *Advances in Mechanics of Structures and Materials: Proceedings of the 17th Australasian Conference (ACMSM17), Gold Coast, Queensland, Australia, 12-14 June 2002*: Taylor & Francis.

Lotfi, F. H., Allahviranloo, T., Jondabeh, M. A., and Kiani, N. (2007). A new method for complex decision making based on TOPSIS for complex decision making problems with fuzzy data. *Applied Mathematical Sciences,* 1(60), 2981-2987.

Lu, G., and Yu, T. (2003). *Energy absorption of structures and materials*: Woodhead Publishing.

Lu, J., and Wool, R. P. (2005). Development of new green SMC resins and nanocomposites from plant oils. Retrieved from http://www.speautomotive.com/SPEA_CD/SPEA2004/pdf/h/h4.pdf

M.C.C. (1989). *LUSAS finite element stress analysis system: theory manual.*

Madenci, E., and Guven, I. (2006). *The finite element method and applications in engineering using ANSYS*. New York: Springer.

Mahmoodzadeh, S., Shahrabi, J., Pariazar, M., and Zaeri, M. (2007). Project selection by using fuzzy AHP and TOPSIS technique. *International Journal of Humanities and Social Sciences,* 1(3), 135-140.

Mair., L. R. (2000). Tomorrow's Plastic Cars. Retrieved Jul-Aug, from Australian Academy of Technological Sciences and Engineering http://www.atse.org.au/index.php?sectionid=433

Mallick, P. K. (2008). *Fiber-reinforced composites: materials, manufacturing, and design*: CRC Press.

Margolis, J. M. (1986). *Advanced Thermoset Composites: Industrial and Commercial Applications*. New York: Van Nostrand Reinhold.

Marzbanrad, J., Alijanpour, M., and Kiasat, M. (2009). Design and analysis of an automotive bumper beam in low-speed frontal crashes. *Thin-Walled Structures,* 47(8-9), 902-911.

Matthew, C. (2009). Motor Vehicle Safety Regulations Retrieved Nov 25, 2010, from http://www.gazette.gc.ca/rp-pr/p2/2008/2008-06-25/html/sor-dors199-eng.html

MatWeb. (2008a). Material Property Data Azdel Plus C401-B01 40% Chopped Fiber Mat / PP Resin Matrix Retrieved Aug 2008

http://www.matweb.com/search/datasheet.aspx?MatGUID=e9348a559e504a8c897ffdc9b83aa232

MatWeb. (2008b). Material Property Data Azdel Plus C401-B01 40% Chopped Fiber Mat / PP Resin Matrix, . Retrieved April 2009 http://www.matweb.com/search/datasheet.aspx?MatGUID=e9348a559e504a8c897ffdc9b83aa232

Maxwell, J. (1994). *Plastics in the Automotive Industry*. Warrendale: Woodhead Publishing.

Mazumdar, S. K. (2002). *Composites Manufacturing: Materials, Product, and Process Engineering*. Boca Raton: CRC Press.

McCabe, E. (2004). PASSENGER CAR BUMPERS - and Federal safety standard 581. Retrieved from www.insurorsservicebureau.com/ISB%20technical/Bumpers_.pdf

MCP. (2001). Pegeout 405 front bumper components. Retrieved July 2008 www.mehrcampars.com

MCP. (2002). Energy absorber of peugeot 405. Retrieved Aug 2007 www.mehrcampars.com

MCP. (2003). GMT bumper beam of Samand. Retrieved July 2008 www.mehrcampars.com

Mehta, G., Mohanty, A. K., Thayer, K., Misra, M., and Drzal, L. T. (2005). Novel biocomposites sheet molding compounds for low cost housing panel applications. *Journal of Polymers and the Environment,* 13(2), 169-175.

Miravete, A. (1993). *ICCM/9: Composites Properties and Applications* (Vol. 6). Zaragoza: Woodhead Pub Ltd.

Mohanty, A., Misra, M., and Drzal, L. (2001). Surface modifications of natural fibers and performance of the resulting biocomposites: an overview. *Composite Interfaces,* 8(5), 313-343.

Mohanty, A., Misra, M., and Drzal, L. (2002). Sustainable bio-composites from renewable resources: opportunities and challenges in the green materials world. *Journal of Polymers and the Environment,* 10(1), 19-26.

Mohanty, A., Misra, M., and Hinrichsen, G. (2000). Biofibres, biodegradable polymers and biocomposites: An overview. *Macromolecular Materials and Engineering,* 276(1), 1-24.

Mohanty., A., Misra, K. M., and Drza, l. L. T. *Surface Modification of Natural Fibers to Improve Adhesion As Reinforcements for Thermoset Composites*. Paper presented at the 24th Annual Meeting of the Adhesion Society-Adhesion Science for the 21 Century.February 25-28 2001

Mohanty., A., Misra, M., and Drzal, L. (2005). *Natural Fibers, Biopolymers, and Biocomposites*. Boca Raton: CRC Press.

Morye, S., and Wool, R. (2005). Mechanical properties of glass/flax hybrid composites based on a novel modified soybean oil matrix material. *Polymer Composites,* 26(4), 407-416.

Mueller, D. H., and Krobjilowski, A. (2003). New discovery in the properties of composites reinforced with natural fibers. *Journal of Industrial Textiles,* 33(2), 111.

Murata, S., Shioya, S., and Suffis, B. (2004). Expanded Polypropylene (EPP): A Global Solution for Pedestrian Safety Bumper Systems.

Murray, N. W. (1994). *When it comes to the crunch: the mechanics of car collisions*: World Scientific.

Mussig, J. (2008). Cotton Fibre-reinforced Thermosets Versus Ramie Composites. *Journal of Polymer Environment,* 8(4).

Mussig, J., and Stevens, C. (2010). *Industrial Applications of Natural Fibres: Structure, Properties and Technical Applications*. Wiltshire: John Wiley & Sons.

Nashed, B., Rice, J., Kim, Y., and Chalivendra, V. (2011). Damage Analysis of Projectile Impacted Laminar Composites. *Dynamic Behavior of Materials, Volume 1*, 427-437.

NHTSA. (1990). National Highway Traffic Safety Administration Laboratory Test Procedure for Regulation Part 581 Bumper Standard Safety Assurance. Retrieved Nov 20, 2010, from http://www.nhtsa.gov/DOT/NHTSA/Vehicle%20Safety/Test%20Procedures/Associated%20Files/TP-581-01.pdf

Nichols, M., and Robertson, R. (1994). The toughness of epoxy-poly (butylene terephthalate) blends. *Journal of Materials Science,* 29(22), 5916-5926.

Nishimura, T. (2006). Development of Car Components Using Kenaf and a New Evolution in Biomaterials. *Society of Automotive Engineers of Japan,* 60(1), 100.

Nishino, T., Hirao, K., Kotera, M., Nakamae, K., and Inagaki, H. (2003). Kenaf reinforced biodegradable composite. *Composites Science and Technology,* 63(9), 1281-1286.

Novahyfo. (2002). Bumper shock absorber. Retrieved from http://www.novahyfo.com

Oksman, K. (2000). Mechanical properties of natural fibre mat reinforced thermoplastic. *Applied Composite Materials,* 7(5), 403-414.

Oksman, K., Wallström, L., and Berglund, L. (2002). Morphology and mechanical properties of unidirectional sisal–epoxy composites. *Journal of Applied Polymer Science,* 84(13), 2358-2365.

Pahl, G., Beitz, W., and Feldhusen, J. (2007). *Engineering Design: A Systematic Approach.* London: Springer

Paiva Junior, C., De Carvalho, L., Fonseca, V., Monteiro, S., and d'Almeida, J. (2004). Analysis of the tensile strength of polyester/hybrid ramie-cotton fabric composites. *Polymer testing,* 23(2), 131-135.

Panthapulakkal, S., and Sain, M. (2007). Studies on the Water Absorption Properties of Short Hemp—Glass Fiber Hybrid Polypropylene Composites. *Journal of Composite Materials,* 41(15), 1871.

Panthapulakkal, S., Shiang, Law., Mohini, Sain. . (2006). Performance of Injection Molded Natural Fiber - Hybrid Thermoplastic Composites for Automotive Structural Applications
SME, 115(5).

Park, D., Jang, C., Lee, S., Heo, S., Yim, H., and Kim, M. (2010). Optimizing the shape of a bumper beam section considering pedestrian protection. *International Journal of Automotive Technology,* 11(4), 489-494.

Patel, S., Gonsalves, K., Stivala, S., Reich, L., and Trivedi, D. (1993). Alternative procedures for the recycling of sheet molding compounds. *Advances in Polymer Technology,* 12(1), 35-45.

Pavithran, C., Mukherjee, P., Brahmakumar, M., and Damodaran, A. (1991). Impact properties of sisal-glass hybrid laminates. *Journal of Materials Science,* 26(2), 455-459.

Pedersen, P. (2008). Suggested benchmarks for shape optimization for minimum stress concentration. *Structural and Multidisciplinary Optimization,* 35(4), 273-283.

Pilkey, W., Pilkey, D., and Peterson, R. (2008). *Peterson's Stress Concentration Factors*. Hoboken: Wiley.

Plackett, D., Løgstrup Andersen, T., Batsberg Pedersen, W., and Nielsen, L. (2003). Biodegradable composites based on-polylactide and jute fibres. *Composites Science and Technology,* 63(9), 1287-1296.

Plastic Omnium. (2001). Material Innovations Retrieved June 2010 http://www.sae.org/automag/material/01-2002/

Pugh., S. (1994). *Total Design.* Cornwall: Addison-Wesley

Qipeng, G., Xinsheng, P., and Zhiji, W. (1991). The miscibility and morphology of epoxy resin/poly (ethylene oxide) blends. *Polymer,* 32(1), 53-57.

Qiu, S., Fok, S., Chen, C., and Xu, S. (2002). Conceptual design using evolution strategy. *The International Journal of Advanced Manufacturing Technology,* 20(9), 683-691.

Rasshofer W., Weigand E., and Frisch C.K. (2001). *Advances in Plastics: Automotive Polyurethanes, Volume II*. Lancaster: Technomic.

Ratna, D. (2007). *Epoxy Composites: Impact Resistance and Flame Retardancy*: Smithers Rapra Technology.

Ray , D., and Rout , J. (2005). Thermoset Biocomposites. A. K. Mohanty , M. Misra andL. T. Drzal (Eds.), *Natural Fibers, Biopolymers, and Biocomposites*. Boca Raton: CRC Press.

RCAR. (2010). RCAR Bumper Test. (2). Retrieved from http://www.rcar.org/Papers/Procedures/BumperTestProcedure.pdf

Reid, S. R., and Zhou, G. (2000). *Impact behaviour of fibre-reinforced composite materials and structures*. London: CRC Press.

Riedel, U., and Nickel, J. (1999). Natural fibre reinforced biopolymers as construction materials–new discoveries. *Die Angewandte Makromolekulare Chemie,* 272(1), 34-40.

Rong, M. Z., Zhang, M. Q., Liu, Y., Yang, G. C., and Zeng, H. M. (2001). The effect of fiber treatment on the mechanical properties of unidirectional sisal-reinforced epoxy composites. *Composites Science and Technology,* 61(10), 1437-1447.

Rosato, D. (1996). Injection molding higher performance reinforced plastic composites. *Journal of Vinyl and Additive Technology,* 2(3), 216-220.

Rosato, D. V., and Murphy, J. (2004). *Reinforced plastics handbook*: Elsevier Advanced Technology.

Rouison, D., Sain, M., and Couturier, M. (2004). Resin transfer molding of natural fiber reinforced composites: cure simulation. *Composites Science and Technology,* 64(5), 629-644.

Rout, J., Tripathy, S., Misra, M., Mohanty, A., and Nayak, S. (2001). The influence of fiber surface modification on the mechanical properties of coir polyester composites. *Polymer Composites,* 22(4), 468-476.

Rowell, R., Caulfield, D., Chen, G., Ellis, W., Jacobson, R., Lange, S., et al. *Recent advances in agro-fiber/thermoplastic composites.* Proceedings of the 2th International Symposium on Natural Polymers and Composites Brazil. 1998.

Saaty, T. (1980). *The analytic hierarchy process: planning, priority setting, resource allocation.* New York: Mc.GrawHill.

Saheb, D. N., and Jog, J. (1999). Natural fiber polymer composites: a review. *Advances in Polymer Technology,* 18(4), 351-363.

Sain, M., Suhara, P., Law, S., and Bouilloux, A. (2005). Interface modification and mechanical properties of natural fiber-polyolefin composite products. *Journal of reinforced plastics and composites,* 24(2), 121.

Samaha, R. R., Molino, L. N., and Maltese, M. R. *Comparative performance testing of passenger cars relative to FMVSS 214 and the EU 96/EC/27 side impact regulations: phase I.* 1998.

Samal, S. K., Mohanty, S., and Nayak, S. K. (2009). Banana/Glass Fiber-Reinforced Polypropylene Hybrid Composites: Fabrication and Performance Evaluation. *Polymer-Plastics Technology and Engineering,* 48(4), 397-414.

Santulli, C. (2007). Impact properties of glass/plant fibre hybrid laminates. *Journal of Material Science,* 42, 3699–3707.

Sapuan, S. M., Leenie, A., Harimi, M. B., and Beng, Y. K. (2006). Mechanical properties of woven banana fibre reinforced epoxy composites. *Materials and Design,* 27 (8), 689–693.

Sapuan, S. M., Maleque, M. A., Hameedullah, M., Suddin, M. N., and Ismail, N. (2005). A note on the conceptual design of polymeric composite automotive bumper system. *Journal of Materials Processing Technology,* 159 145–151.

Schmueser, D., and Wickliffe, L. (1987). Impact energy absorption of continuous fiber composite tubes. *Journal of engineering materials and technology,* 109, 72.

Schuh, T., G. . (2000). Renewable materials for automotive applications. Retrieved from http://www.ienica.net/fibresseminar/schuh.pdf

Schuster, P. J. (2006). Current trends in bumper design for pedestrian impact. *SAE Technical Papers.*

Shalaby, S. W., and Monroe, L. A. (1998). Functionalized crystalline polyactones as toughners for thermosetting resins: Google Patents.

Shanian, A., and Savadogo, O. (2006). TOPSIS multiple-criteria decision support analysis for material selection of metallic bipolar plates for polymer electrolyte fuel cell. *Journal of Power Sources,* 159(2), 1095-1104.

Sharpe, N., Vendrig, R., and Houtzager, K. (2001). Improved design for frontal protection. *TNO Automotive.*

Sherman, L. M. (2004). Where the Action Is: Decorating with Formable Films. Retrieved 2008, from Plastic Technology http://www.ptonline.com/articles/where-the-action-is-decorating-with-formable-films

Shibata, S., Cao, Y., and Fukumoto, I. (2008). Flexural modulus of the unidirectional and random composites made from biodegradable resin and bamboo and kenaf fibres. *Composites Part A: Applied Science and Manufacturing,* 39(4), 640-646.

Shih, H., Shyur, H., and Lee, E. (2007). An extension of TOPSIS for group decision making. *Mathematical and Computer Modelling,* 45(7-8), 801-813.

Shin, M., Yi, S., Kwon, O., and Park, G. (2008). Structural optimization of the automobile frontal structure for pedestrian protection and the low-speed impact test. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering,* 222(12), 2373-2387.

Singh, B., Gupta, M., and Verma, A. (1995). Mechanical behaviour of particulate hybrid composite laminates as potential building materials. *Construction and Building Materials,* 9(1), 39-44.

Sjoblom, P., and Hwang, B. *Compression-after impact: The $5,000 data point.* Proceedings of the 34th International conference SAMPE, Nevada.May 8-11 1989.

Smith, H. (1998). About the Kenaf Plant. (15 June). Retrieved from http://www.visionpaper.com/kenaf2.html.

Smith, K. L., and Suh, N. P. (1979). An approach towards the reduction of sink marks in sheet molding compound. *Polymer Engineering & Science,* 19(12), 829-834.

Sreekala, M., Kumaran, M., Joseph, S., Jacob, M., and Thomas, S. (2000). Oil palm fibre reinforced phenol formaldehyde composites: Influence of fibre surface modifications on the mechanical performance. *Applied Composite Materials,* 7(5), 295-329.

Stewart, R., Osterman, A., and Jalbert, D. (1992). Vehicle and bumper beam combination: Google Patents.

Stewart, R., Osterman, A., Jalbert, D., and Nulty, J. (1994). Vehicle bumper beam: Google Patents.

Suddell, B. C., and Evans, W. J. (2005). Natural Fiber Composites in Automotive Applications. A. Mohanty., M. Misra andL. Drzal (Eds.), *Natural Fibers, Biopolymers, and Biocomposites.* Boca Raton: CRC Press.

Suddell., D. B. (2003). The Current Situation and Future Outlook for Natural Fibres within the Automotive Industry (Vol. 2008). Salvador, Brazil.

Suddin, M., Din, A., Abdullah, M., and Shamsudin, S. *Conceptual design of automot ive bumper beam.* Proceedings of the design, simulation,product development and optimization, Penang.10-11 December 2007.

Suddin, M. N., Salit, M. S., Ismail, N., and Abd, M. (2004). Total design of polymer composite Automotive Bumper fascia. *Journal of Science Technology,* 12(1), 39-45.

Sun, C., and Chattopadhyay, S. (1975). Dynamic response of anisotropic plates under initial stress due to impact of a mass. *ASME Journal of Applied Mechanics,* 42(9), 693-698.

Surhone, L. M., Tennoe, M. T., and Henssonow, S. F. (2010). *Product Design Specification*: VDM Verlag Dr. Mueller AG & Co. Kg.

Tao, W., Calamari, T. A., Shis, F. F., and Cao, C. (1997). Characterization of kenaf fiber bundles and their nonwoven mats. *Tappi Journal,* 80(12), 162-166.

TATA Steel. (2003). Crash integrated bumper beam. Retrieved from Mar 2008 website: http://www.corusautomotive.com/en/products/chassis_and_suspension/hydro forming/services/examples/bumper_beam/>

Teng, K. C., and Chang, F. C. (1996). Single-phase and multiple-phase thermoplastic/thermoset polyblends: Morphologies and mechanical properties of phenoxy/epoxy blends. *Polymer,* 37(12), 2385-2394.

Terry, D. S. (2001). Structural RIM Choices for Today's Automotive Design. Retrieved June 2009, from Bayer Polymers LLC http://www.speautomotive.com/SPEA_CD/SPEA2003/pdf/i01.pdf

The Eropean allience for SMC. (2001). SMC/BMC Design for Success. Retrieved Oct 2008, from Georg Knopf Druck GmbH http://www.smc-alliance.com

Throne, J. L. (1998). Processing Thermoplastic Composites. G. Lubin andS. T. Peters (Eds.), *Handbook of composites*: CRC Press.

Thwe, M. M., and Liao, K. (2003). Durability of bamboo-glass fiber reinforced polymer matrix hybrid composites. *Composites Science and Technology,* 63(3-4), 375-387.

Tolinski, M. (2005). Glass Fiber Meets Stiffer Competition. *Plastics Engineering,* 61(3), 18-20.

Tong, L., Mouritz, A. P., and Bannister, M. K. (2002). *3D fibre reinforced polymer composites*: Elsevier.

Trevor, F. S. (1999). *Composites: A Profile of Worldwide Reinforced Plastics Industry, Markets and Suppliers* (3th ed.). Oxford: Elsevier

Tucker, N., and Lindsey, K. (2002). *An Introduction to Automotive Composites.* Shropshire: Rapra Technology Limited.

U. Riedel. *Technical and Economical Framework for Parts Based on Natural Fibre Composites.* Proceedings of the 8th International AVK-TV Conference for Reinforced Plastics and Thermoset Moulding Compounds, Baden-Baden.September 27–28 2005.

Vaidya, U. (2010). *Composites for Automotive, Truck and Mass Transit: Materials, Design, Manufacturing*. Lancaster: DEStech Publications, Inc.

Van Voorn, B., Smit, H., Sinke, R., and De Klerk, B. (2001). Natural fibre reinforced sheet moulding compound. *Composites Part A: Applied Science and Manufacturing,* 32(9), 1271-1279.

Varma, I., Krishnan, S. R. A., and Krishnamoorthy, S. (1988). Effect of chemical treatment on thermal behavior of jute fibers. *Textile research journal (USA)*.

Varna, J., Joffe, R., Akshantala, N., and Talreja, R. (1999). Damage in composite laminates with off-axis plies. *Composites Science and Technology,* 59(14), 2139-2147.

Velmurugan, R., and Manikandan, V. (2007). Mechanical properties of palmyra/glass fiber hybrid composites. *Composites Part A: Applied Science and Manufacturing,* 38(10), 2216-2226.

Voyiadjis, G. Z., and Kattan, P. I. (2006). *Advances in damage mechanics: metals and metal matrix composites with an introduction to fabric tensors*: Elsevier.

Wambua, P., Ivens, J., Verpoest, I. . (2003). Natural fibres: can they replace glass in fibre reinforced plastics? *Journal of Composite Science Technology,* 63(9), 1259-1264.

Wang, L., Shen, W., Xie, H., Neelamkavil, J., and Pardasani, A. (2002). Collaborative conceptual design--state of the art and future trends. *Computer-Aided Design,* 34(13), 981-996.

WBCSD. (2004). Meeting the Challenges to Sustainability (Mobility 2030) (pp. 176). Geneva: World Business Council for Sustainable Development.

Weon, J. I., and Choi, K. Y. (2009). Surface Characterization and Morphology in Ar-Plasma-Treated Polypropylene Blend. *Macromolecular Research,* 17(11), 886-893.

Wielage, B., Lampke, T., Utschick, H., and Soergel, F. (2003). Processing of natural-fibre reinforced polymers and the resulting dynamic-mechanical properties. *Journal of Materials Processing Technology,* 139(1-3), 140-146.

Wijskamp, S. (2005). *Shape distortions in composites forming: proefschrift*. Enschede: l'autor.

Williams, G. I., and Wool, R. P. (2000). Composites from natural fibers and soy oil resins. *Applied Composite Materials,* 7(5), 421-432.

Wong, D. W. Y., Lin, L., McGrail, P. T., Peijs, T., and Hogg, P. J. (2010). Improved fracture toughness of carbon fibre/epoxy composite laminates using dissolvable thermoplastic fibres. *Composites Part A: Applied Science and Manufacturing,* 41(6), 759-767.

Woodhams, R., Thomas, G., and Rodgers, D. (1984). Wood fibers as reinforcing fillers for polyolefins. *Polymer Engineering & Science,* 24(15), 1166-1171.

Xiao, A., Park, S., and Freiheit, T. (2007). A comparison of concept selection in concept scoring and axiomatic design methods.

Yim, H. J., Kim, M. S., Park, J., Heo, S. J., and Park, D. K. (2005). Shape Optimization of Bumper Beam Cross Section for Low Speed Crash. *SAE Technical Papers*.

Zaini, M., Fuad, M. Y. A., Ismail, Z., Mansor, M., and Mustafah, J. (1996). The effect of filler content and size on the mechanical properties of polypropylene/oil palm wood flour composites. *Polymer international,* 40(1), 51-55.

Zampaloni, M., Pourboghrat, F., Yankovich, S., Rodgers, B., Moore, J., Drzal, L., et al. (2007). Kenaf natural fiber reinforced polypropylene composites: A discussion on manufacturing problems and solutions. *Composites Part A: Applied Science and Manufacturing,* 38(6), 1569-1580.

Zaouk, A., Marzougui, D., and Kan, C. (2000). Development of a detailed vehicle finite element model Part II: Material characterization and component testing. *International Journal of Crashworthiness,* 5(1), 37-50.

Zhang, X., Xu, W., Xia, X., Zhang, Z., and Yu, R. (2006). Toughening of cycloaliphatic epoxy resin by nanosize silicon dioxide. *Materials Letters,* 60(28), 3319-3323.

Zhang, Z., Liu, S., and Tang, Z. (2009). Design optimization of cross-sectional configuration of rib-reinforced thin-walled beam. *Thin-Walled Structures,* 47(8-9), 868-878.

Zhang , Z., Liu, S., and Tang, Z. (2009). Design optimization of cross-sectional configuration of rib-reinforced thin-walled beam. *Thin-Walled Structures,* 47(8-9), 868-878.