



The Mechanical Properties Requirement for Polymer Composite Automotive Parts - A Review

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Abstract. Indonesia has a large variety of natural fibers in abundance. Some of natural fibers become organic waste if not used for something needed by humans. One of the potentials uses of natural fiber composite materials is to be used in automotive components. But before natural fiber composites are used in automotive components, it is necessary to examine first what are the requirements for mechanical properties or other properties required by the automotive components. Especially the automotive components which have been made from Polymers, like dashboard, Car interior walls, front and rear bumper and Car body, etc. Each of these automotive components has different function and condition, and that caused different mechanical properties needed. The purpose of this study is collecting the data from the literature, related to the properties needed for these automotive components. This study was conducted by studying the literature of research journals in the last 10 years. From the research journals, data on the requirements of mechanical properties for automotive components will be collected. Furthermore, the data of mechanical properties required for automotive components can be used as a reference to determine the reliability of automotive components made from composite.

Keywords: natural fiber; mechanical properties; automotive components; composite; polymer

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1. Introduction

Indonesia has various kinds of natural fibers both from plants and animals. Especially for natural fibers derived from plants the amount is very abundant. The natural fibers which much available in Indonesia are oil palm fiber, coconut fiber, palm fiber, sugar cane fiber and so on. Most of these natural fibers come from various or by-products from food plants that cannot be consumed. So that often these natural fibers become heaps of organic waste if not used for something needed by humans.

One of the natural fibers available where almost everywhere in Indonesia is coconut fiber. The availability of coconut fiber in the country of Indonesia is very abundant. This is due to the fact that Indonesians consume large amounts of coconut for cooking and other purposes. On the other hand, the huge consumption of coconut certainly also produces very large amounts of organic waste from coconut fiber, and tends to increase the volume of waste if it is not processed into something useful for humans. Therefore it is necessary to do various researches to utilize coconut waste to be something that is more beneficial for humans.

Although synthetic fiber reinforced composite materials are still being researched and developed [1], natural fibers have enormous potential to be used as reinforcement in composite materials. There are many studies that have been done in this regard. Such as research on adding water hyacinth fiber to concrete [2] and other research studies to make automotive components [3][4][5].

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There have been many studies conducted by researchers around the world about the use of composite materials in automotive components, especially in the interior and exterior of cars which are usually made from polymers [3] Most of the reinforcement used in these composite materials are synthetic fibers such as fiberglass or carbon fiber (Carbon fiber) [6]. Although the use of natural fibers as reinforcement in composite materials has been widely studied, its utilization is still limited. Because natural fibers have their own advantages and disadvantages compared to synthetic fibers that have been widely used. Therefore the potential for using natural fibers as reinforcement in composite materials for automotive components still needs to be researched and developed in order to replace the synthetic fibers used today.

However, before coconut fiber composite is used for the automotive components, it is necessary to conduct prior examine about the mechanical properties requirement or other properties required by the automotive components in order to make sure the safety of using this fiber. The automotive components investigated here were the front and rear bumper, the body of the car, dashboard and interior walls of the car.

In this study several problem boundaries are used to limit the scope of the research to be conducted. The limitations of these problems include:

1. Research is carried out by means of research literature studies conducted by researchers in the world, especially the last 20 years.
2. Automotive components are limited as follows:
 - a. For exterior components limited only to the front and rear bumper and the car body.
 - b. For interior components limited only to the dashboard and interior walls of the car.

The objectives of this study are:

1. Obtain the properties needed by the exterior components of the car including the front and rear bumpers and body.
2. Obtain the properties needed by the interior components of the car including the dashboard and interior walls.
3. Ensuring that natural fiber reinforced polymer composite materials are capable of possessing properties according to the criteria required by automotive components.

It is expected that this research will obtain a complete data on the need for material properties in automotive components so that in the future it can be developed the use of coconut fiber composite materials for automotive components.

2. Research Methodology

2.1 Research flowchart

The flowchart of this research is shown in the Figure 1.

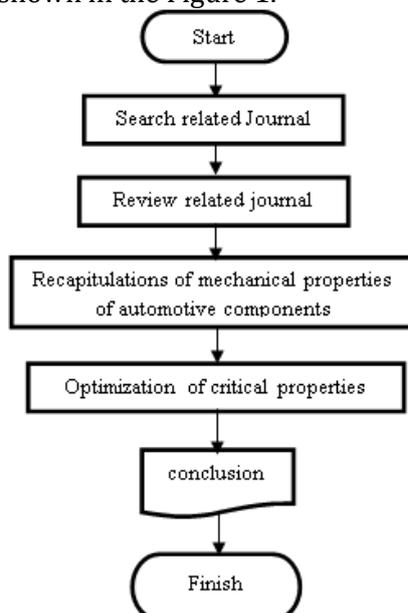


Figure 1. Research flow chart

2.2 Steps of research work

The research begins with searching research journals related to the mechanical properties needed for automotive components. Furthermore, a review of the journal is carried out to obtain the characteristics needed by the automotive component, to be recapitulated. Furthermore, a conclusion is made and suggestions were given regarding the mechanical properties.

2.3 Reference review

The number of reviewed was more than 40 references, consisting of books and journals. The reviewed journals are those from nationally accredited journals or reputable international journals (scopus indexed).

2.4 Recapitulation of mechanical properties and optimization of critical properties

Recapitulation of mechanical properties is grouped according to the part of the automotive component studied. The components to be examined are divided into the following:

- 1) Exterior components, consisting of a car body, front and rear bumper.
- 2) Interior components, consisting of: Dashboard and interior walls.

The recapitulation was made in the form of tables so that it was easily understood by other researchers who would later conduct research related to the mechanical properties of automotive components.

3. Results and Discussions

There are four areas requires highest priority research and development with plastic i.e.: interior, body and exterior, powertrain and chassis and the last is light weighting [3].

- 1) Interior: Priorities for improving safety including enhancing safety belt designs and reducing package space.
- 2) Body and exterior: research activity including energy management technologies that resist vehicle intrusion impede roof crush and reduce body and exterior weight while still prioritizing safety performers.
- 3) Powertrain and chassis: optimize safety and fuel efficiency and developing the new safety components.
- 4) Light weighting: The new high performers component that lower the center of gravity of a vehicle, need to be developed to enhance pedestrian safety and to improve crash of avoidance and performer system.

Hovorun et. Al. [4] investigated modern Material for Automotive industry. This Study conclude that the car manufacturers continue to push to create cars as light as possible and increase power and speed. Therefore, research and development of lightweight materials for automotive components is very important not only to reduce costs, but also to increase their ease of recycling and maximize economic benefits. Current and future conditions, the automotive industry will continue to bring light and strong material innovation to the frontline of design.

Among static and quasi-static testing and measuring methods, the tensile test is regarded as the fundamental test in mechanical material testing [8]. Impact strength is the fracture resistance of a material subjected to a high speed from a few meters per second to several kilometers per second where the loading duration to fracture is quite short. The Charpy or notch Charpy Impact test is a common test for evaluating the toughness of plastic under Impact loading [8].

From previous research, the mechanical properties of composite materials is also influenced by the percentage of fiber content. When the content of natural fiber is too low, it will not have a significant effect on the mechanical properties of the composite material [9].

Physical and mechanical properties of natural fibers are influenced by their chemical compositions. Every type of natural fiber has different chemical composition as shown in Table 1.

Table 1. shows the chemical composition of common natural fibers. From the table, it is possible to see that cellulose comprises the highest percentage for almost all types of natural fiber. As explained in this section, the molecular structure of cellulose is responsible for its supramolecular structure, which in turn determines many of the physical and chemical properties [11].

Table 1. Chemical compositions of common natural fibers [10]

Types of Natural Fiber	Cellulose (wt%)	Hemicellulose (wt%)	Lignin (wt%)	Waxes (wt%)
Bagasse	55.2	16.8	25.3	-
Bamboo	26-43	30	21-31	-
Flax	71	18.6-20.6	2.2	1.5
Kenaf	72	20.3	9	-
Jute	61-71	14-20	12-13	0.5
Hemp	68	15	10	0.8
Ramie	68.6-76.2	13-16	0.6-0.7	0.3
Abaca	56-63	20-25	7-9	3
Sisal	65	12	9.9	2
Coir	32-43	0.15-0.25	40-45	-
Oil Palm	65	-	29	-
Pineapple	81	-	12.7	-
Curaua	73.6	9.9	7.5	-
Wheat Straw	38-45	15-31	12-20	-
Rice Husk	35-45	19-25	20	14-17
Rice Straw	41-57	33	8-19	8-38

The Research and development for introducing composites in automotive parts in order to reduce the vehicle mass have been studied by some researcher. Grabowski et al. [5] have studied the composite material molding simulation for purpose of automotive industry. The object of that study is power steering's body of vehicle, which previously used only metal. That study found that the geometry of current power steering's body needs to be improved, since the directions and distributions of fiber influenced the mechanical properties of composite materials [5]. Overview of current research on the use of natural fiber composites for automotive components has been conducted [12]. Their conclusion are as follows:

1. Natural fiber aspects

Judging from the price of raw materials, natural fiber is cheaper compared to synthetic fibers such as glass fiber and carbon fiber. Comparison of fiber prices (in US \$ / kg) is as follows: 200 carbon fiber, glass fiber 1.3-3.25, sisal 0.6-0.7, abaca 1.5-2.5, flax 1.25-2.5, coconut fiber 0.25-0.5, jut 0.30-0.35, flax 1.5, hemp 0.6-1.8 [13,14].

2. Natural fiber research for composites

Strengthening natural fibers in polymers increases the strength properties between 2 ~ 5 times depending on the amount of fiber.

3.1 Process technology

The process commonly used to make automotive component composites is hot press molding [15] and injection molding [15]. Polypropylene is widely used in injection molding processes using natural fibers [16,17,18,19].

Oil palm fiber have been studied extensively for the production of composites for various applications, such as, cement boards[20], energy absorption applications [21], concrete beam [22], as glass fiber substitutes [23] and also for automotive parts [24,25]. The effect of oil palm shell (OPS) powder on the mechanical performance and thermal stability of polyester composites were investigated by other researcher [26]. The effect of washing OPS powder in methanol to remove surface impurities was investigated with tensile and flexural strengths. The result showed that the composite tensile and the flexural strength generally increased with decreasing powder size; the strength of the composite containing powder with sizes of 75 – 150 μm was similar to that of the pure matrix. However, the tensile and flexural moduli of the composite were found to be essentially independent to powder size. Thermogravimetric analysis (TGA) in flowing oxygen indicated that the addition of OPS powder shifted the thermal degradation peak of the bio composite from 370°C to

480°C. The fiber–matrix adhesion in a composite can be improved by treating the fiber. The fiber can be treated with chemicals such as methanol [26].

Currently, some automotive parts have used natural fiber composites, including seat back panels, side and door panels, instrumental panels, headliner panels, dashboards, boot linings, hat racks, spare tire covers, business tables, pillar panel covers, underbody trim. Among the automotive industry that have utilized natural fiber as a component include Audi, BMW, Volvo, Daimler Chrysler, Ford, Mitsubishi, Opel, Peugeot, Renault, Saab, Volkswagen, Fiat. [14,27].

Automotive components that have used natural fibers include side and door panels, hatrack, seat back, dashboard, boot lining, spare tire lining, pillar cover panels, under body protection trim, instrumental panels, etc. strengthening of natural fibers in polymers can increase their strength 2-5 times depending on fiber composition.

Some of the advantages of using natural fibers compared to synthetic fibers (fiber glass) for automotive components include refinement (renewable), and sustainable, can be recycled (recyclable), can reduce vehicle weight 10-30%, available in large quantities and cheaper [27].

3.2 *The mechanical properties of the interior component (dashboard and interior wall)*

Investigation Automotive product design and development of car dashboard using quality function development has been conducted [28]. This study concludes that the quality of the plastic, the texture and the color of the car dashboard materials should be improved to help the company catch up with its competitors. The recommended materials for the dashboard are polycarbonate, acrylonitrile butadiene styrene, polypropylene, and styrene maleic anhydride. The quality of the dashboard trim is one of the qualities that must be maintained on the dashboard to suit customer requirements. Besides having to be strong and sturdy to withstand vibrations and not cause noise, the material used for car dashboards must also be light so that fuel efficiency is better. Vehicles that are more fuel efficient will certainly make customers more satisfied. Customers also need dashboards that are highly resistant to wear, especially due to frequent friction parts such as switch knobs and glove boxes that regularly / the amount of time used in a day. The company must provide good quality materials consisting of highly resistant properties such as polycarbonate or polypropylene [28].

Herwandi et al. [29] investigated about improved quality of recycled fiber for composite materials as motorized vehicle materials. They come to their conclusion as follow:

From the tensile, flexure and impact testing process the maximum results obtained for tensile stress 24.4MPa, elastic modulus 6686MPa, strain 0.38%, flexure / bending stress 94.85MPa, flexural modulus 4141.5MPa, and impact voltage 55,81 kJ/m². The dashboard technical specifications are the reference:

- The tensile strength of ABS high impact plastic materials is 20-40MPa.
- Modulus of elasticity of plastic material ABS high impact between 1-2.5 GPa (1000-2500)MPa.
- The strain value of ABS high impact plastic material is 2%.
- The stress value of ABS high impact plastic material is 37-76MPa.
- The value of the flex modulus of ABS high impact plastic material is 1235-2588MPa.
- For ABS plastic material impact strength is 13.48 kJ/m².

All the results of this testing process when compared to the standard plastic used for the car dashboard turned out to meet the standards, so that it can be used as one of the new composite materials for the car dashboard.

3.3 *The mechanical properties of car bumper*

Properties of polymers such as corrosion resistance, low density, chemical resistance and generally good Impact toughness, along with other specific physical, chemical, electrical and mechanical properties encourage their usage in the automotive industry [3]. Most modern automobile bumper systems incorporate a significant proportion of polymeric materials[3].

Research on car bodies has been conducted by many researchers. Some of them investigated the crash safety [30] and some of them investigated the material used for car body [31] and some of them both of crash safety and material used [32] or design of a conceptual bumper energy absorber coupling pedestrian safety and low speed impact requirement [33]. Others researcher study about natural fiber as reinforce of composite material for car body [34].

Typical automobile bumper systems, depending upon design, may contain three major components: a bumper cover, a bumper support, and an energy absorbing system. usually, bumper covers are made from polymeric materials. the bumper support, and the energy absorbing system can be made from steel, but are increasingly made from polymeric materials [3].the polymers used for bumper covers on most modern vehicles are either thermoset polymer (polyurethane or polyuria) or thermoplastic (such as a blend of polypropylene/ polyethylene and propylene) or polycarbonate/polyester. Polymers used in this fashion have a specific performance requirement such as excellent low temperature impact toughness, dimensional stability, excellent surface appearance, and if unpainted, good long term weatherability and photo oxidative stability [3, 35]

Research on the use of composite materials for vehicle bumpers has been carried out [36]. from this study it was found that the specific energy absorption shown by the composite is comparable to that of an aluminum bumper beam. the results of observations, there was a mass reduction of about 56%. Approximately 90% of the peak force required for the initiation of damage to the composite bumper beam is reduced with an extension of the impact time of approximately 89%. The historical velocity curve shows a lower rate of retarding can be obtained through the use of a composite bumper beam [36].

Analyze study about composite car bumper reinforcement has been conducted. The study concluded that the main advantage of a composite bumper over real steel, was a 78% reduction in mass. [37].

A review the development process of new bumper beam for passenger car has been conducted [38]. The bumper beam should full fill the structural test to get the final approval which include mechanical test such as tensile and compressive strange toughness and yield strange with a consideration of environmental condition like humidity (20-95%) and temperature -30°C to 85°C. there are two type of impact test i.e., low speed impact test and high speed impact test. The low speed impact test are different between in European countries and American countries in European countries a pendulum test at 4 km/h with no damage to the bumper, and in USA and North America the same test at 8 km/h but the damage to the fascia is not consider. After the test, any damage should not occur to bumper visual and functional. The high speed impact test should meet the OEM's internal bumper standard in design stash. The design criterion for a high speed impact for bumper system are as follows:

- After 8 km / h frontal impact to a flat rigid barrier the result is no bumper damage.
- For all impact speeds, less than 15 km / h, there is no disturbance to the bumper system at the rear of the engine compartment, rails.
- In order to reduce the possibility of lateral bending of the rails, it is necessary to minimize the lateral loads during impact
- Full system failure during high-speed Danner (RCAR), NCAP and IIHS without induction support on rails.

A Comparative study of automotive bumper with different material for passenger and pedestrian safety has been conducted [39]. The study concluded that:

1. Compared to steel, carbon fiber provides a high strength to weight ratio and saves energy.
2. The basic design with front part as a foam absorbed the energy and ensures pedestrian safety.
3. The Struture of honeycomb has the strength to absorb more energy thereby reducing the crate thus ensuring the safety of passengers.

Investigation about the impact on car bumper-by literature review has been conducted [40]. An international RCAR working group has developed test procedures to assess how well a vehicle's bumper system protect, the vehicle from damage in low speed impact. Damage in this test closely replicates the damage pattern observed in real world low speed crash and addresses three components of bumper performance:

- Geometry-vehicle bumpers need to be positioned at common height from the ground and extend laterally the corner in order to properly engage other vehicles in low speed crashes.
- Stability-vehicle bumpers need to be tall and wide enough engage with the bumpers of other vehicles despite vehicle motion due to loading, breaking, etc.
- Energy absorption- Vehicle bumpers should absorb low speed crash energy without damage to other parts of the vehicle.

The majority of modern plastic car bumper system fascia are made of thermoplastic olefins (TPO), polycarbonate, polyesters, polypropylene, polyurethanes, polyamides, or blends of these with, for instance glass fiber for strength and structural rigidity.

Investigation about natural fiber composite for bumper material have been conducted [41]. This study found that kenaf hybridization of the bio composite bumper beam, which would be developed to replace the current bumper beam material, does not fully meet the required impact properties. However, in this study it was found that the striped bumper beam can reduce the deflection of the bumper beam by 11% and reduce the stress energy by 11.3%. Therefore, it can be relied on for the utilization of automotive structural components [41].

4. Conclusion

The conclusions of this study are as follows:

- 1) Material used for bumpers and car body should be able to manage energy, which is resistant to vehicle intrusion, inhibits roof destruction, and reduces body weight and exterior without reducing safety performance.
- 2) Properties required on the dashboard:
 - a. The tensile strength of high-impact ABS plastic materials is 20-40 MPa.
 - b. Modulus of elasticity of ABS plastic materials has a high impact between 1-2.5 GPa (1000-2500) MPa.
 - c. The strain value of high-impact ABS plastic material is 2%.
 - d. The stress value of high impact ABS plastic materials is 37-76 MPa.
 - e. The high modulus value of high-impact plastic material is 1235-2588 MPa.
 - f. The impact strength of ABS plastic material is 13.48 kJ/m
- 3) Partially strengthened polymeric polymer composite materials can already meet the criteria for the properties required by automotive components, but most still need further research so that the properties can be improved.
- 4) Research on natural fibers as composite materials for automotive component applications and the use of natural fiber in automotive products have been presented in this paper. The use of natural fibers for automotive part, not only having various advantages, but also has several drawbacks, therefore it still needs further investigation, in order to obtain a natural fiber composite that meets the standards for automotive use.

Recommendations

Base on the result of this research, recommendation from the author as follow:

- 1) It is needed to more investigations regarding the other mechanical natural fiber resin composite in order to expand the applications of natural fiber composite in structural or machine component.
- 2) It is important to investigate natural fiber composite by varying the matrix material type.

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