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# Comparison-based Analysis of Epoxy Resin Using Core-shell Rubber

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***Author's contribution***

*The sole author designed, analysed, interpreted and prepared the manuscript.*

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## ABSTRACT

The main objective of this study was to compare the reactivity and mechanical characteristics of unfilled epoxy resin with those which are modified using core-shell rubber. Detailed experimentation consisting of various mixtures of core-shell rubber with epoxy resin was carried out by varying the quantity of CSR in the mixture ranging from 5 to 15wt% and then allowing it to heat for 10-15 mins in a heating mantle at 40 degrees Celsius. This combination was then mixed with a hardener in a ratio of 2:1. The sample was cured for 24 hours and then the mechanical properties and reactivity were tested.

For both categories of samples, the testing of mechanical properties was conducted and it was observed that fracture toughness increased by almost 3 times with the addition of 15wt% CSR to epoxy. At the same time, impact strength increased to nearly 1.5 times and tensile strength decreased linearly with the addition of Core-shell rubber to the mixture.

However, the testing revealed that samples that contained the addition of CSR showed better mechanical properties, exhibiting high toughness and high resistance to crack propagation while a decrease in gel time and cure time was recorded.

*Keywords: Core-shell rubber; epoxy resin; reactivity; mechanical properties.*

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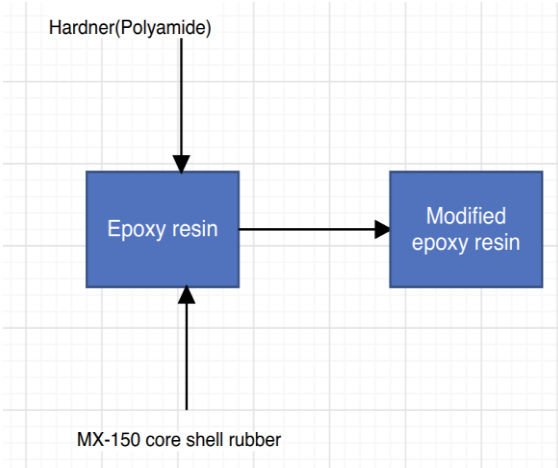
## 1. INTRODUCTION

Epoxy resins are classified as a class of thermosetting polymers, which are widely used in adhesives, paints, coatings, and construction projects. They are recognized for offering high modulus and strength. Such cross-linking, however, results in unfavorable characteristics such as brittleness, inadequate resistance to crack propagation, lower impact resistance, and low flexibility. This issue could be solved using liquid reactive rubber-like ATBN or using a Core-Shell Rubber, however, in this paper we will focus on CSR [1,2]. These particles have a rigid polymer shell surrounding a soft rubbery center. Before being disseminated into the epoxy resin, the particles are created using emulsion polymerization, allowing for control of particle size [3-5]. Additionally, it has been shown that CSR particles are remarkably durable, remain evenly dispersed in the epoxy, and boost fracture toughness without altering the epoxy's glass transition temperature. Core shell rubber works on a two-fold mechanism, the core is majorly designed of siloxane, acrylic, or polybutadiene, which provides excellent impact resistance and helps to improve toughness. While the shell is designed to make it compatible with the thermosetting resin [6-8]. The newly processed MX-150 CSR leads to No agglomeration and provides excellent stability. The study focuses on two working aspects, one to analyze the mechanical and chemical properties of modified epoxy resin and the other to understand the working principle of Core-shell rubber along with how a definite amount or proportion of CSR could produce targeted epoxy resin for wider applications, in automotive, aerospace, floor coating, etc [9,10]. Some well-known tests like the Izod impact test, fracture toughness along with tensile strength were performed to compare with unfilled epoxy resin [11,12]. The later stage of the paper also covers a few aspects related to the toughening mechanism of epoxy resin and the effect of CSR on gel time and cure time.

## 2. MATERIALS AND METHODS

### 2.1 Materials Used

Diglycidyl ether bisphenol A (DGEBA) YD 128, (Astral Adhesive, India) epoxy resin with molecular weight 382, an epoxy index of 5.15-5.40 Eq/kg, and an epoxy equivalent of 185-194 g/Eq. The curing agent is Polyamide (Astral Adhesive, India) and the modifying agent is liquid reactive rubber with a core-shell made of Polybutadiene MX-150 of CSR content of 40wt% (Kaneka, Texas).




**Flow chart 1. Block representation of an experimental study**

### 2.2 Methodology

Test A: In a standard 2: 1 ratio, epoxy resin, and curing agent were mixed. Test B: In this test resin and rubber were first mixed and then heated at 40-50oC for 10 mins using a heating mantle. The main purpose of heating the mixture was to get a homogeneous mixture of resin and rubber. Similarly, polyamide was heated for 2-3 mins at 40oC to reduce its viscosity and make its mixing easier. Now, the mixture and polyamides were mixed in a standard ratio of 2:1 and cured in a plastic mold, which is then cured for 24 hours at room temperature.

### 2.3 Mechanical Testing

#### 2.3.1 Fracture toughness

The ability of a material to withstand fracture under specific situations is referred to as its fracture toughness. For this purpose, fracture toughness was measured using single-edge notched specimens in three-point bending. It was observed that the addition of CSR particles into epoxy resin improved the fracture toughness and it could be possible because of the reaction taking place between CSR and epoxy matrix at the interface. From the scatter plot, it is evident that there is a threefold increase in fracture toughness from approximately 0.5 MPam½ to 1.5MPam½. Moreover, CSR particles reduce inherent stress that is generated during curing thus improving the fracture toughness of the material.

#### 2.3.2 Tensile strength testing

Tensile strength is the maximum stress that a material can support without breaking when it is stretched, divided by the area of the material's original cross-section. However, With the addition of CSR particles, it was observed that there was a linear decrease in the tensile strength of the material. A possible reason for this could be as we increase the volume fraction of CSR from 0wt% 15wt%, the stiffness of epoxy reduces and hence the tensile strength decreases. So, an optimum range of core-shell rubber of nearly about 4-5wt% Could be beneficial in providing sufficient tensile strength to the material.

#### 2.3.3 Izod impact test

Impact testing is performed to determine the impact resistance or toughness of a material when subjected to sudden shock or load. For this purpose, an Izod test was performed where the specimen was held on a vertical cantilever beam and was broken by a pendulum. The Izod impact test was performed on different sample strips having different proportions of rubber. It was observed that adding about 10-15% of CSR increased the impact strength by 1.5 times. From 78J/m to nearly 116 J/m. This behavior could be because of improved adhesion between CSR and epoxy resin due to chemical reactions and also the particle size of CSR that improves the impact properties.

#### 2.3.4 Chemical reactivity

Gel time and Cure Time: The cross-linking of epoxy with polyamides as a curing agent as well as the addition of CSR accelerates the reaction and decreases the cure time significantly but at the same time, the addition of a greater amount of CSR will cause steric hindrance inside the epoxy matrix that will lead to a reduction of the exothermic peak. Moreover, on heating the mixture of CSR and epoxy resin, it starts reacting and thus, releases heat as it's an exothermic reaction. Hence, the influence of CSR will reduce the gel time as compared to unmodified epoxy resin.

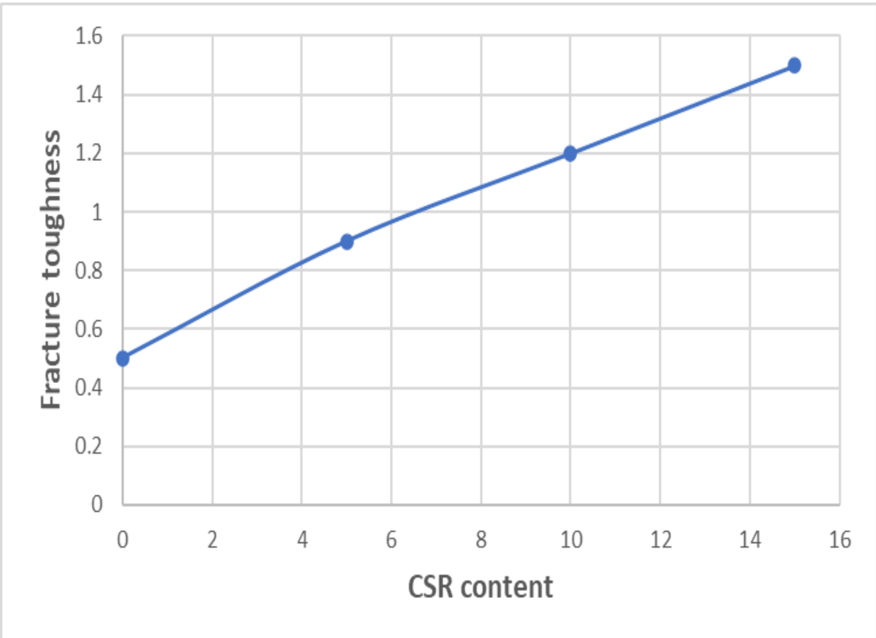



**Fig. 1. Effect of CSR content on fracture toughness of epoxy resin**

**Table 1. Effect of CSR content on the chemical reactivity of epoxy resin**

| Rubber (%) | Gel Time(mins) | Cure time(mins) | Gel Temp(degree celsius) | Exothermic Peak(degree celsius) |
|---|---|---|---|---|
| 0 | 30 | 38 | 88 | 100 |
| 5 | 20 | 25 | 86 | 98 |
| 10 | 18 | 22 | 85 | 95 |
| 15 | 16 | 21 | 79 | 90 |

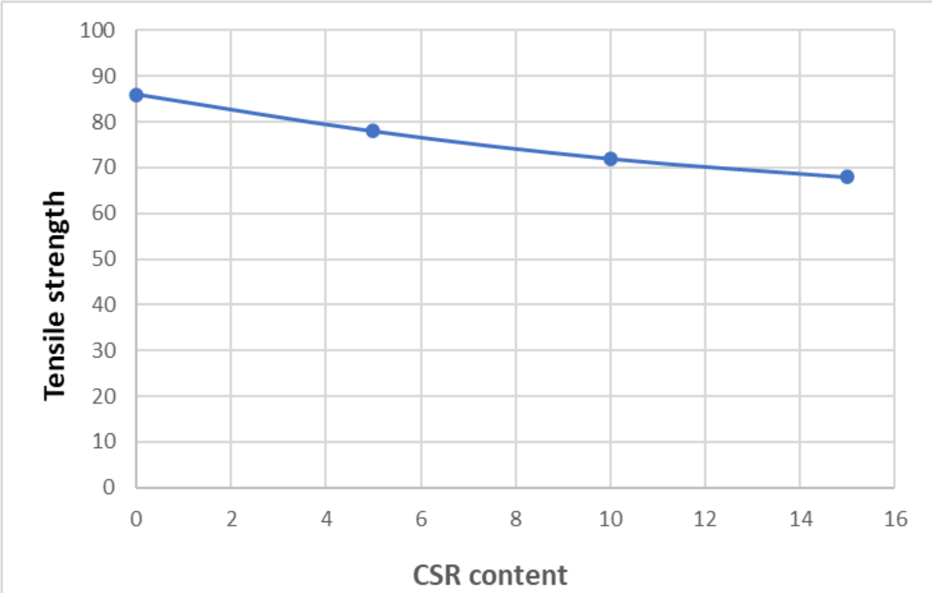



**Fig. 2. Effect of CSR content on Tensile strength of epoxy resin**

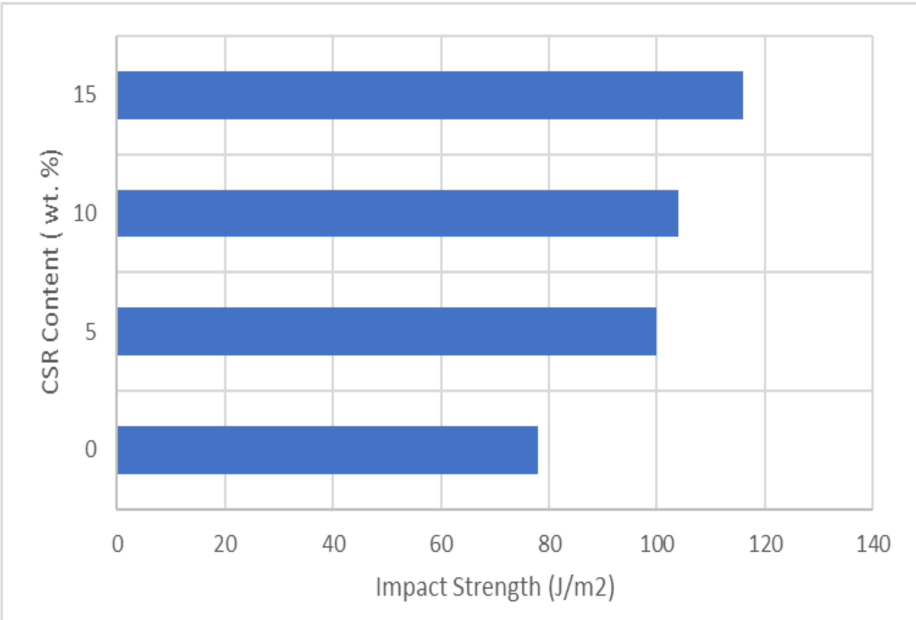



**Fig. 3. Effect of CSR content on the impact strength of epoxy resin**

## 3. RESULTS AND DISCUSSION

From the experimental testing, we found that adding even a small amount of core-Shell Rubber in epoxy could increase the fracture toughness by 3 times and impact strength by 1.5 times. But at the same time, tensile strength starts to decrease, so an optimum range of CSR, around 5-7% could solve the overall performance of epoxy resin to a great extent. Thus, it is concluded that the small and finely divided rubber particles act as the crack terminator, which increases the inter-laminar bond and strength of the material. The images taken from the optical microscope show the surface morphology of epoxy resin when mixed with different proportions of core-shell rubber. It's quite conclusive that even a small proportion of CSR could enhance the surface morphology of epoxy resin.

Fig. 4(a). 0wt% CSR

Fig. 4(b). 5wt% CSR

## 4. CONCLUSIONS

Based on the results obtained, it’s worth mentioning that the reaction of CSR particles and epoxy matrix at the interface leads to improved fracture toughness as interfacial adhesion is achieved. Additionally, the composition's overall strength is increased by the fine dispersion of CSR particles within the epoxy matrix. Moreover, due to the reduction in phase separation by introducing CSR, the toughening mechanism is created due to small voids present due to the cavitation of the rubber particles and debonding at the particle interface, which enhances the fracture toughness as well as the impact strength of the material. From mechanical and chemical testing, we can conclude the addition of nearly 5-7% of core-shell rubber into resin along with a suitable hardener could improve the properties to a greater extent along with other benefits like no agglomeration and reduced damaged area.

## COMPETING INTERESTS

Author has declared that no competing interests exist.

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