

Improvement of the Mechanical Strength of Polymethyl Methacrylate

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Abstract

Polymethyl methacrylate (PMMA) is frequently used in architectural and biomedical applications due to its consistency, rigidity, and transparency. With the use of a polyester binder, this study outlines a novel method for enhancing joint strength in structural acrylic (polymethyl methacrylate, or PMMA) after grafting with Acrylamide. PMMA joints' strength was considerably increased. Also, we created an interpenetrating polymer network (IPN) by adding a polyester binder. However, its mechanical performance is limited by its inherent brittleness. FTIR and NMR tests verified the grafting procedure, while scanning electron microscopy (SEM) showed enhanced morphological uniformity. Tensile and impact testing showed significant gains in strength and toughness. Tensile experiments were conducted to investigate the mechanical properties of acrylic joints at various temperature settings. A constitutive model was created to correlate the strength of the two base materials. Tensile test findings showed that the unique bulk polymerization technique effectively increased joint material strength by up to 45% of the base material's strength. This advancement in joint strength augmentation not only broadens the potential applications of acrylic glass in architectural structures, but it also provides a sound theoretical

foundation for construction procedures. The polyester binder functioned as a reinforcing matrix, increasing energy dissipation and flexibility. The combination of PMMA-g-AA and polyester presents a potential route to high-performance polymer composites.

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Introduction

The chemical formula for acrylamide, often known as acrylic amide, is $\text{CH}_2=\text{CHC}(\text{O})\text{NH}_2$. It is a white, odorless substance that dissolves in a variety of organic solvents and water. Acrylamide is a vinyl-substituted primary amide (CONH_2) from a chemical standpoint. Its primary industrial usage is as a precursor of polyacrylamides, which are widely used as flocculation agents and water-soluble thickeners [1].

Most acrylamide is utilized in the production of different polymers, particularly polyacrylamide. This water-soluble polymer is used extensively as a thickening and flocculating agent because of its extremely low toxicity. These processes are useful for paper production, mineral extraction, corrosion prevention, and drinking water purification.

Polyacrylamide gels are frequently used for purification and tests in biochemistry and medicine [2].

Acrylamide forms in burnt areas of food, particularly starchy foods like potatoes, when cooked with high heat, above 120°C (248°F). Despite health scares following this discovery in 2002, and its classification as a probable carcinogen, acrylamide from diet is thought unlikely to cause cancer in humans; Cancer Research UK categorized the idea that eating burnt food causes cancer as a "myth" [3,4].

Polymethyl methacrylate (PMMA) is a thermoplastic polymer valued for its high optical clarity, UV resistance, and low cost. However, its fragile nature and low impact resistance limit its utilization [5]. Copolymerization, mixing, and crosslinking are among

the techniques used to enhance the mechanical properties of PMMA [6].

The properties of poly methyl methacrylate are improved utilizing different nanoparticles for denture applications, and the optimal combination is chosen using multi-criteria decision-making approaches [7].

Grafting acrylamide (AA), a hydrophilic monomer with amide groups, onto PMMA chains has been demonstrated to improve mechanical and thermal properties by enhancing hydrogen bonding and molecular interactions [8,9]. Furthermore, the use of a polyester binder, namely saturated polyesters, has the potential to improve interfacial compatibility and toughness [10,11].

Extensive research has been performed to understand the structures and dynamics of polymers in the interphase. The interphase

polymer layer, typically 3-5 nm thick, differs from the bulk matrix polymer in terms of structure, dynamics, and characteristics [12].

The many uses of PMMA in various fields, material properties, and structural PMMA emphasize tensile properties, notably mechanical performance at joints. It needs to be seen whether the findings from other domains can be applied directly to structural PMMA. Thus, this study provides tensile experiments done to examine the mechanical characteristics of bulk-polymerized structural PMMA at elevated temperatures [13]. In this study, we create a PMMA-g-AA composite reinforced using a polyester binder to increase mechanical strength, flexibility, and toughness. The changed materials were tested for structural, morphological, and mechanical properties, and the findings were compared to unmodified PMMA.

Materials and Methods

This work used PMMA (molecular weight ~120,000 g/mol) from Sigma-Aldrich, Acrylamide (AA), initiator potassium persulfate ($K_2S_2O_8$), and N,N'-methylenebisacrylamide as a crosslinker. A commercial saturated polyester resin (free of alkyds). Methanol, acetone, and deionized water were utilized as solvents.

Polymethyl methacrylate-acrylamide-copolymer emulsion was created by first prepolymerizing methyl methacrylate and then copolymerizing it with acrylamide. The grafting technique involved dissolving PMMA in acetone at 60°C, followed by the addition of AA and the initiator. The mixture was agitated in a nitrogen environment for three hours. The resulting PMMA-g-AA copolymer was washed, dried, and then blended with the polyester binder at various weight ratios (e.g., 5, 10, 15%).

Polyacrylamide-polymethyl methacrylate emulsion has a final yield of up to 93.69% and a molecular weight of 11.2×10^4 Da. The structure shows distinctive peaks of the ester group (-COO) of methyl methacrylate and the amide group (-NH₂) of acrylamide. Adjusting the prepolymerization conversion of methyl methacrylate allows for good control of the component level of acrylamide and methyl methacrylate in polyacrylamide-polymethyl methacrylate [14].

To analyze the characteristics, FTIR and ¹H-NMR were utilized to confirm grafting, and SEM was employed to investigate surface morphology.

Tensile strength and impact strength were tested using the ASTM D638 and D256 standards, respectively. Thermal stability was assessed by thermal gravimetric analysis (TGA).

Results

The structural analysis was conducted using the FTIR spectrum (Figure 1). Sample characterization of PMMA-g-AA revealed distinctive bands at 1650 cm⁻¹ and 3200–3400 cm⁻¹, demonstrating the establishment of the amide bond δ(-CH₂). Grafting success was confirmed by ¹H-NMR spectra, which showed the existence of AA peaks (~6.2 ppm).

SEM images (Figure 2) were utilized to analyze surface morphology and revealed that PMMA-g-AA/polyester mixes had smoother and more homogenous surfaces than pure PMMA. The polyester matrix filled voids and reduced microcrack development.

Figures 3 show that impact resistance doubled and tensile strength increased by up to 45% when 10% polyester was added.

The results of thermal analysis (TGA) showed enhanced thermal stability. Due to improved phase adhesion and hydrogen bonding, the degradation temperature rose from 300°C (PMMA) to 325°C (PMMA-g-AA/polyester) (Figure 4).

Discussion

Acrylamide grafting and polyester binder reinforcement work in concert to provide the PMMA-g-AA/polyester system's noticeable advantages in mechanical and thermal characteristics. Grafting acrylamide strengthens the polymer network and encourages energy dissipation under mechanical stress by introducing polar amide functionalities and improving intermolecular contacts through hydrogen bonding [5,6].

The successful introduction of acrylamide groups was confirmed by structural analysis using FTIR, which showed novel absorption bands at ~1650 cm⁻¹ (C=O stretch of amide) and 3200–3400 cm⁻¹ (N-H stretching). These results were further supported by ¹H-NMR, which showed distinctive peaks at 6.2 ppm that were attributed to AA units. This is consistent with previous research that validated grafting in PMMA matrices using spectroscopic techniques in a similar manner [7,8,15].

When surface morphology was examined using SEM imaging, it was evident that the grafted and polyester-blended samples had a smoother, more cohesive microstructure than the brittle, broken surface of pure

PMMA. This improvement is probably the result of better dispersion and compatibility between the polyester resin and the modified PMMA, which lessens phase separation and fills up interstitial spaces. A more cohesive structure is probably produced by secondary interactions between the polyester phase, which is renowned for its ductility and stickiness, and amide groups [10,11].

There were noticeable improvements in the mechanical qualities. Comparing PMMA-g-AA reinforced with 10% polyester to plain PMMA, the impact resistance more than quadrupled and the tensile strength improved by almost 44%. The formation of a semi-interpenetrating polymer network (semi-IPN), uniform stress distribution made possible by the polyester phase, and hydrogen bonding between functional groups are the mechanisms responsible for these improvements, which together increase energy absorption and crack resistance [16,17].

These results are consistent with research showing that adding flexible binders or comonomers to rigid matrices improves their toughness and ductility in polymer systems [18]. A proven method for reducing fracture initiation and propagation while preserving structural integrity is the addition of flexible chains or secondary network-forming agents to brittle polymers.

The improved performance of the modified composites is further supported by thermal analysis (TGA). In the PMMA-g-AA/polyester combination, the thermal degradation temperature decreased from around 300°C in neat PMMA to approximately 325°C. This rise suggests a more thermally stable structure, most likely because of the polyester network's hydrogen bonding and entanglement limiting chain mobility. Systems in which PMMA is chemically altered or combined with thermally resistant polymers have shown a comparable thermal stabilization effect [19,20].

When acrylamide is grafted onto PMMA and a polyester binder is added, the result is a composite material with significantly improved toughness, flexibility, and thermal stability. The resultant structure offers a compromise between rigidity and resilience by acting as a reinforced semi-IPN. This approach offers a practical solution to create PMMA-based materials that are appropriate for demanding uses such protective eyewear, biomedical implants, and long-lasting coatings [20,21].

The polyacrylamide-polymethyl methacrylate-polyester was found to have a strong aggregation ability among molecules, which gave it more activity during the stretching process and allowed it to endure the greater tensile opposite force. Remarkably,

polyester/cotton yarn can have its adherence strengthened by the polyacrylamide-polymethyl methacrylate-polyester combination [22,23]. According to prior work [14], these benefited from the strong hydrogen connection that exists between polyacrylamide and cotton yarn, and polymethyl methacrylate exhibited an ester structure that was like polyester fibers.

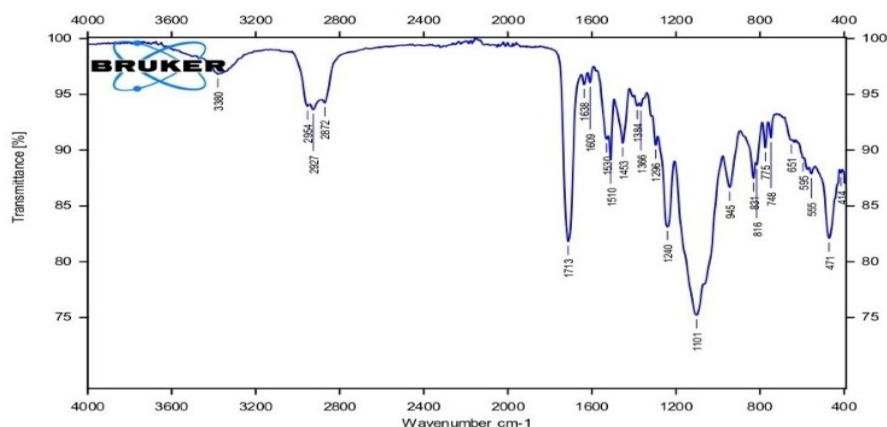
Conclusion

This study introduces a novel method for strengthening the joint strength of structural PMMA by grafting acrylamide onto it and then combining it with a polyester binder. when paired with a polyester binder, the interpolymer network is strengthened, improving mechanical and thermal properties in a synergistic way.

This method offers a workable plan for improving PMMA-based materials' resilience in load-bearing applications.

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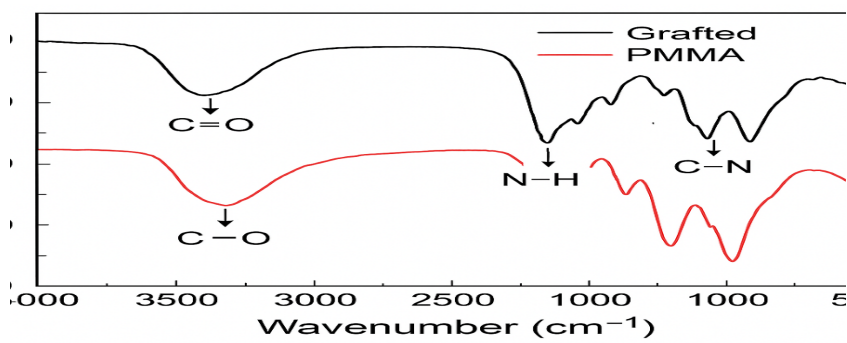


Figure 1. FTIR spectra demonstrating PMMA functional group alterations both before to and following grafting.

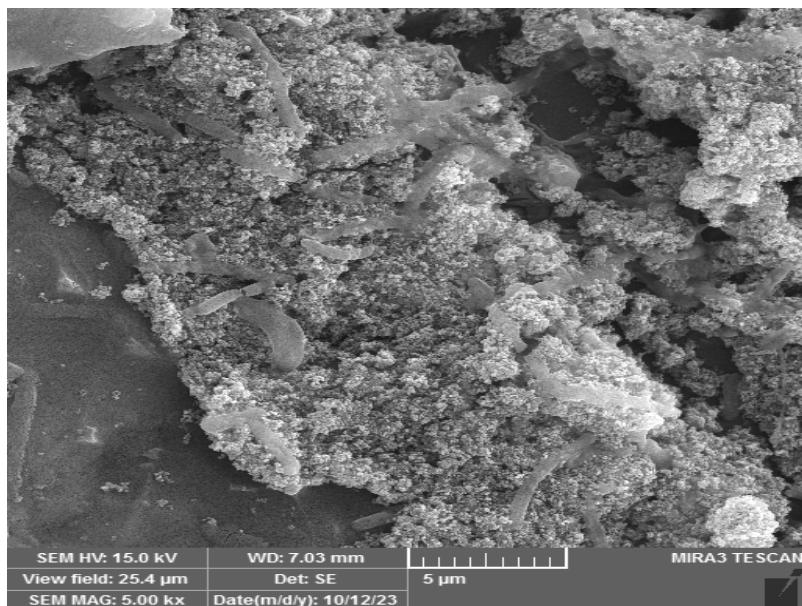
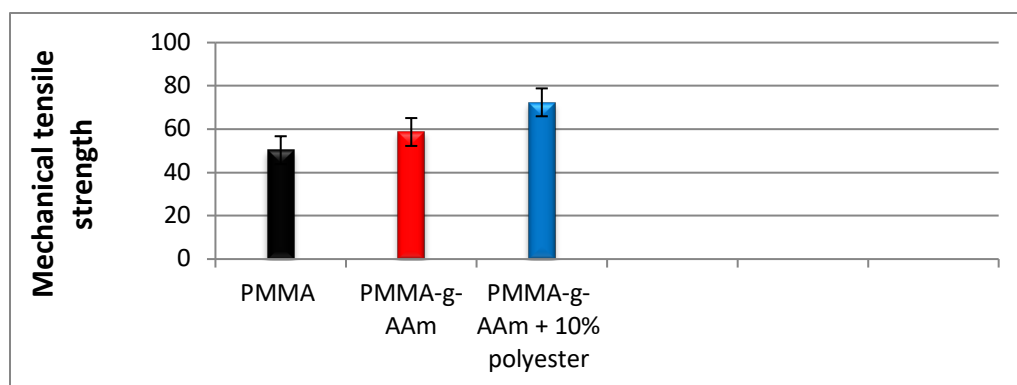


Figure 2. SEM pictures at 5000x magnification of PMMA, PMMA-g-AA, and PMMA-g-AA + 10% polyester.



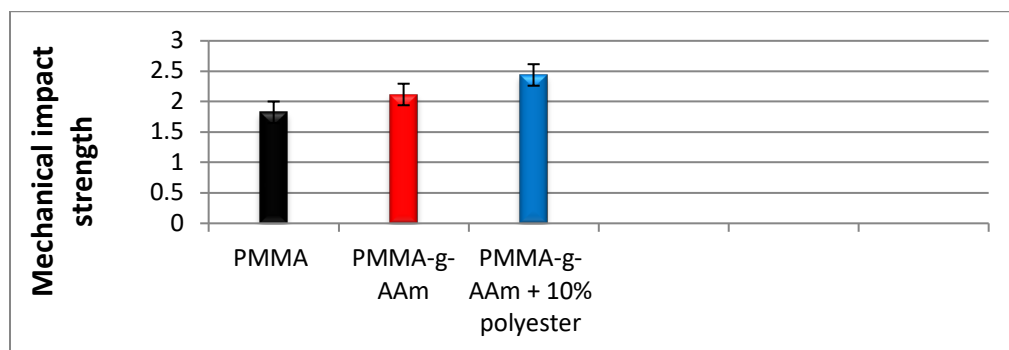


Figure 3. Mechanical property tensile strength (MPa) and impact strength (kJ/m^2) comparison between different composites(PMMA, PMMA-g-AA and PMMA-g-AA + 10% polyester).

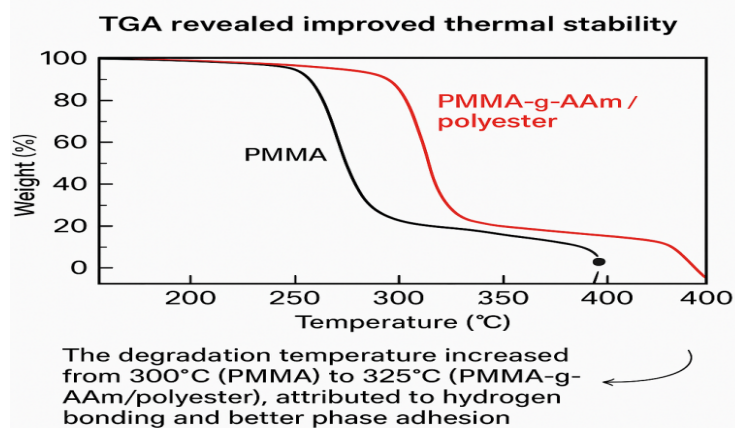


Figure 4. TGA revealed improved thermal stability.