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Modification of Unsaturated Polyester Resin : A Review

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Abstract – In the last few years, the research activity in composite based on modified unsaturated polyester resin and their structures are remarkably increased. This paper is a review of a modification in unsaturated polyester resins. Due to its great performance in a variety of industries, including construction, marine, aerospace, sports goods, offshore applications, fire resistant components, waterlines, and building construction. Unsaturated polyester resin composites are among the most affordable thermoset polymers. This paper aims to review the recent modifications in synthesis, reactive diluents and composites with the conclusion of future scope.

Keywords – Modified Polyester Resin, Synthesis, Reactive diluent, Composites.

1. Introduction

Polyester resins are thermosetting polymers and cure exothermically. Polyester is produced in large quantities more than 30 billion pounds a year all over the world. They are frequently used in industry as fibers, composites and coatings. They are hetero-chain macromolecules and a crucial part of their polymer backbones are carboxylate ester groups. Numerous advantages of polyester resin include its low cost, adequate resistance to water and many chemicals, durability to corrosion and weathering, reasonable temperature resistance, good wetting of glass fiber, low shrinkage during curing and moderate thermal expansion of liner.

There are four types of polyester resin (i) Saturated polyester resin (ii) Alkyd resin (iii) Vinyl ester resin and (iv) Unsaturated polyester resin. (i) Saturated polyester resins are the products of the reaction between di-basic acids or di-basic acid chlorides and diols and they are extensively employed in the textile industry, such as Polyethylene Terephthalate. They are used to manufacture powder coatings for the automobile industry, home appliances, and industrial machinery. (ii) Alkyd resins are the products of polyhydric alcohols and fatty acids, which react with alkyds and then with di-basic acids. They are mostly used by the paint and ink industries. (iii) Vinyl ester resin is the product of epoxy resin esterified with acrylic or methacrylic acids. Due to its resistance to corrosion and capacity to endure water absorption, it is a widely used resin in the marine sector. (iv) Unsaturated polyesters are condension polymers produced when polyols, or polyhydric alcohols, which are organic molecules having numerous alcohol or hydroxyl functional groups, combine with unsaturated and saturated dibasic acids. The polyester backbone's ability to incorporate numerous kinds of moieties enables the customization and manufacture of various resins for a range of uses. Durable unsaturated polyester resins (UPRs) with low viscosity are needed to fabricate downstream industrial items at an exponential rate. Less viscosity, however, often compromises some key properties of cured materials, including lower hardness and weaker heat endurance [1,2]. In the absence of reinforcements, the cured unsaturated polyester resin have high glass transition temperatures and is too brittle for most technical applications. The fiber-reinforced plastic sector makes wide spread use of unsaturated polyester resin due to its inexpensive price, outstanding soaking characteristics, moldability, flexibility, and processibility over a broad range of temperatures, great dimensional rigidity and the broad variety of grades are developed. Unsaturated polyester resin is an important class of thermoset polymers. Unsaturated polyester resin has some drawbacks that restrict its use, including low water resistance, solvent resistance, heat resistance and mechanical properties. However, the modification of unsaturated polyester resin improves toughness, impact strength, network cross-linking, flexibility, corrosion resistance, crack resistance, thermo-oxidative resistance, lower shrinkage, and high-performance components for marine and aerospace industries.

2. Modification of Unsaturated Polyester Resin

Unsaturated Polyester Resin has endured modification to become nano-composites, composites, interpenetrating polymer networks (IPNs), blends and more.

Unsaturated polyester resins are blended with a variety of materials to enhance their fracture and impact resistance. The end groups of unsaturated polyester resin chains may become inactive during reactive blending with thermoset resins. It has been reported that unsaturated polyester resin and other thermosets can be chemically modified by reactively blending into semi interpenetrating polymer networks (IPNs) and hybrid polymer networks (HPNs). Many research investigations have been investigated on the combination of epoxy resin with polyesters to produce IPNs [3,4,5,6]. Unsaturated polyester matrixes modified by vinyl ester oligomers, interpenetrating networks made with variable bis-malemide percentages have been produced [7]. Hybrid polymer networks made of unsaturated polyester and polyurethane pre-polymers are also being investigated [8,9,10,11,12,13]. Similar to this, using methacrylate end-capped nitrile rubber, epoxy-terminated nitrile rubber or isocyante end-capped polybutadiene to chemically bond the elastomer and unsaturated polyester resin is a promising approach. The rubber-like stage that is randomly distributed throughout substance as a result of the modification of resin with elastomeric compounds yields high absorption energy after influence failure. Unsaturated polyester resin can be modified physically and chemically with the aid of toughening chemicals. Rubbers are dissolved in the resin during physical modification. As phase- separated blends are often more durable than homogenous blends, these additives should be miscible in the uncured resin, and phase separation during curing is crucial. Long- chain glycols or long- chain saturated di-acids can be used for resin synthesis to carry out chemical changes [14]. Due to their low shrinkage and low styrene content dicyclopentadiene-modified unsaturated polyester resins have rapidly increased in commercial uses. When compared to conventional unsaturated polyester, they also provide more process ability, enhanced thermo-oxidative resistance, and lower linear shrinkage. Advanced components for the water-based and industrial sectors, including fenders, sealing panels, shell panels, ship hulls, the decks, coatings, adhesives are best made with dicyclopentadiene-modified polyester resins [15,16,17]. Unsaturated polyester resin modified with acrylic monomers has strong thixotropic, flexibility, and crack resistance [18]. To satisfy the demanding properties of a modification of unsaturated polyester resin, this paper aims to provide an overview of current modifications made in polyester resin by scientific endeavors as well as find various appropriate materials and procedures used for modification.

3. Synthesis of modified unsaturated polyester resin

3.1 Modification of unsaturated polyester hybrid network with Epoxy

Reactive blending was used to produce hybrid polymer networks (HPNs) made of epoxy resins and unsaturated polyester resin (UPR). Epoxidized phenolic novolac (EPN), Epoxidized cresol novolac (ECN), and glycidyl ether of bisphenol-A were used as epoxy resins (DGEBA). Epichlorohydrin was used to glycidylate novolacs to produce epoxy novolacs. The reaction mechanism of epoxy-modified unsaturated polyester hybrid networks show in figure-1. [19].

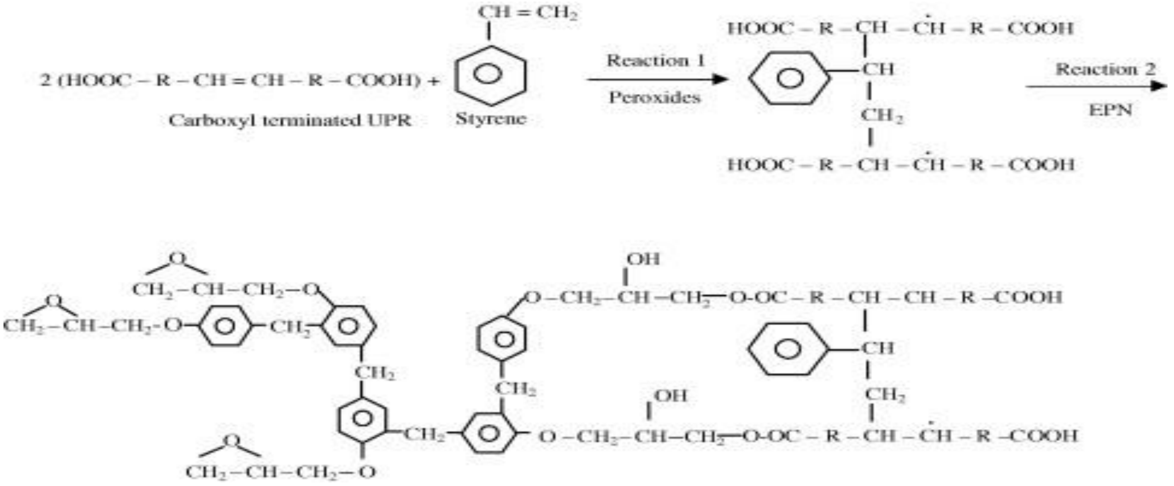


Figure-1.Reaction Mechanism of epoxy-modified unsaturated polyester hybrid unsaturated polyester hybrid network. Reproduced with permission from Ref. 19

3.2 Modification of unsaturated Polyester Resin with Bismaleimide-

The modification of unsaturated polyester resin with 4,4'-bismaleimidodiphenyl-methane (BM). Orthophthalic be used for producing commercial unsaturated polyester called D-1103.The modification procedure includes two steps:-Unsaturated polyester was used to develop identical BM solutions in the first step and polystyrene was used to decompose them in the second step. Figure -2 Represent the reaction among the unsaturated polyester, styrene and BM [20].

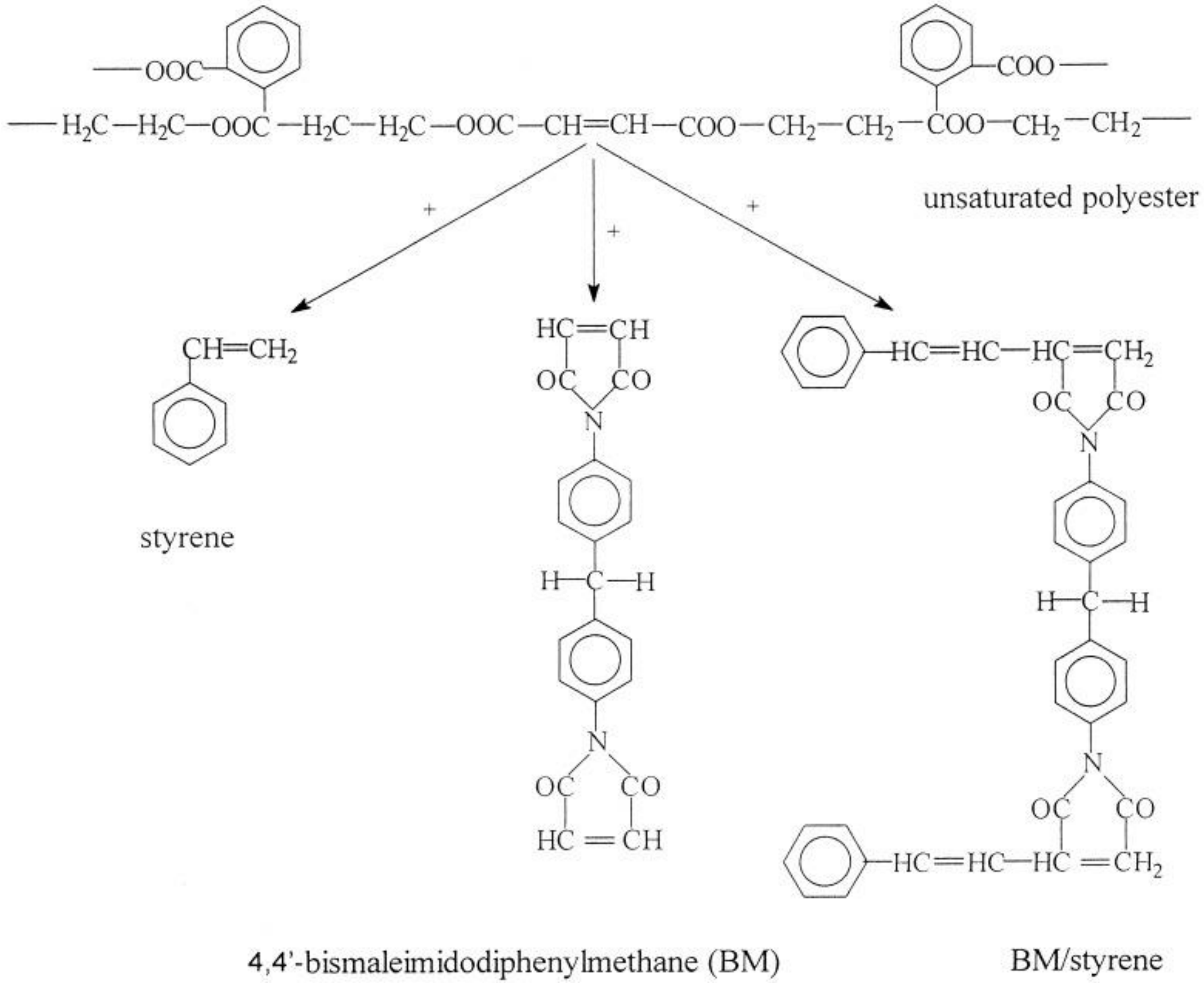


Figure-2 Represent the reaction among the unsaturated polyester, Styrene and BM Reproduced with permission from Ref. 20

4. Synthesis of Modified Bio-Based Unsaturated Polyester Resin

4.1 Modification of Dicyclopentadiene-terminated unsaturated polyester resins by using tung oil-

Tung Oil (TO) modified unsaturated polyester resin that was terminated with dicyclopentadiene (DCPD-UPR) by an intermolecular Diels-alder reaction. The modification procedure has three steps: First step Synthesize dicyclopentadiene-maleate (DCPD-MA) via hydrolysis. Second Step Melt poly-condensation was used to synthesize unsaturated polyester resin that has been modified by DCPD it is called DCPD-UPR. The third step followed by second step DCPD-UPR were added certain amount (for instance, 16.7g) of tung oil in drop by drop till the acid value of the reacting mixture dropped to 60-70 mg KOH/g [21].

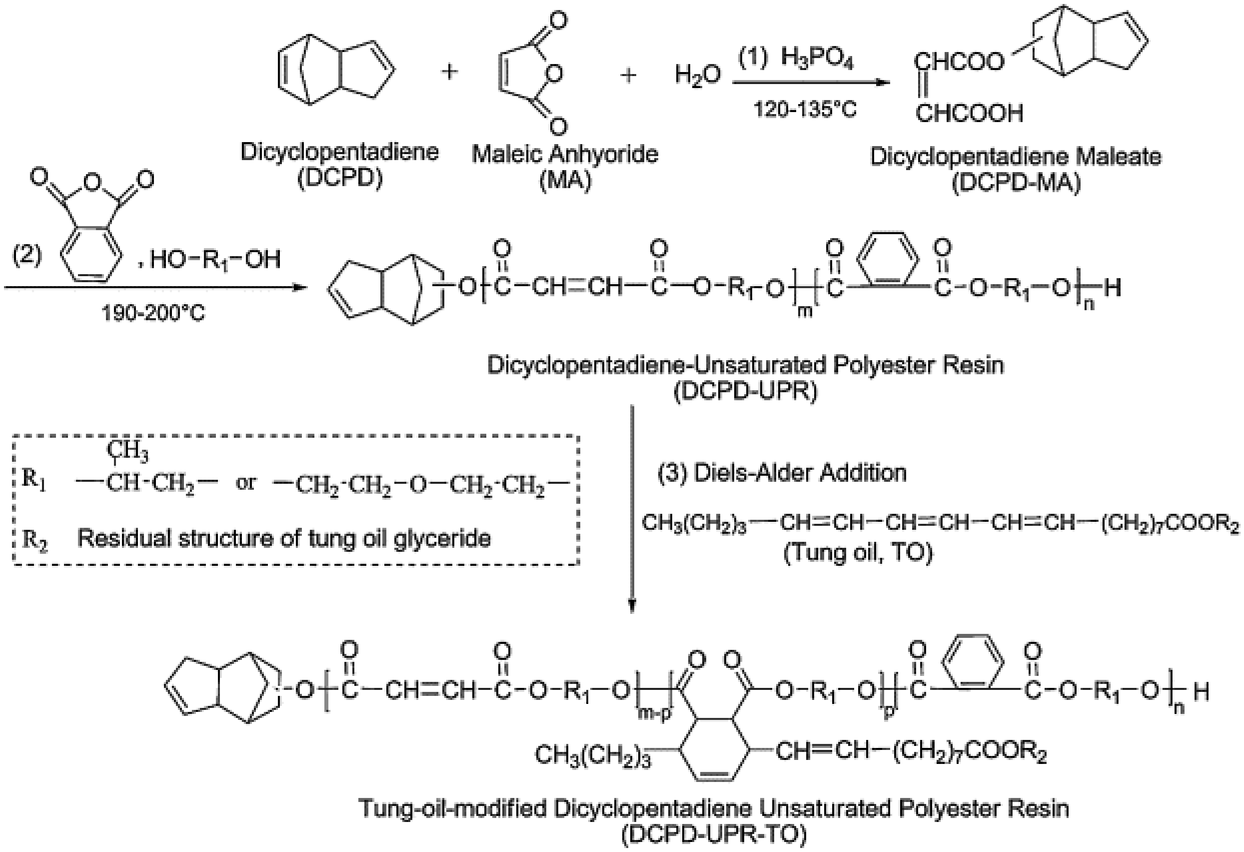


Figure-3 Reaction Mechanism of Tung-oil-modified Dicyclopentadiene Unsaturated Polyester Resin. Reproduced with permission from Ref. 21

4.2 Modification of unsaturated polyester resin with Itaconic acid-based acrylic-monomers

To synthesize polyester polyol, polyhydric alcohol, such as NPG (Neopentyl glycol), DEG (Diethylene glycol), and TMP (Trimethyol propane), and a polybasic acid, such as IPA (isophthalic acid) and AA (Adipic acid) was condensed. After that, polyester resin and unsaturated polybasic acid interacted to produce an unsaturated polyester resin intermediate with a carbon-carbon double bond. To include unsaturation sites into the polyester backbone. Figure-4 Shows the modification of polyester with acrylic monomers.

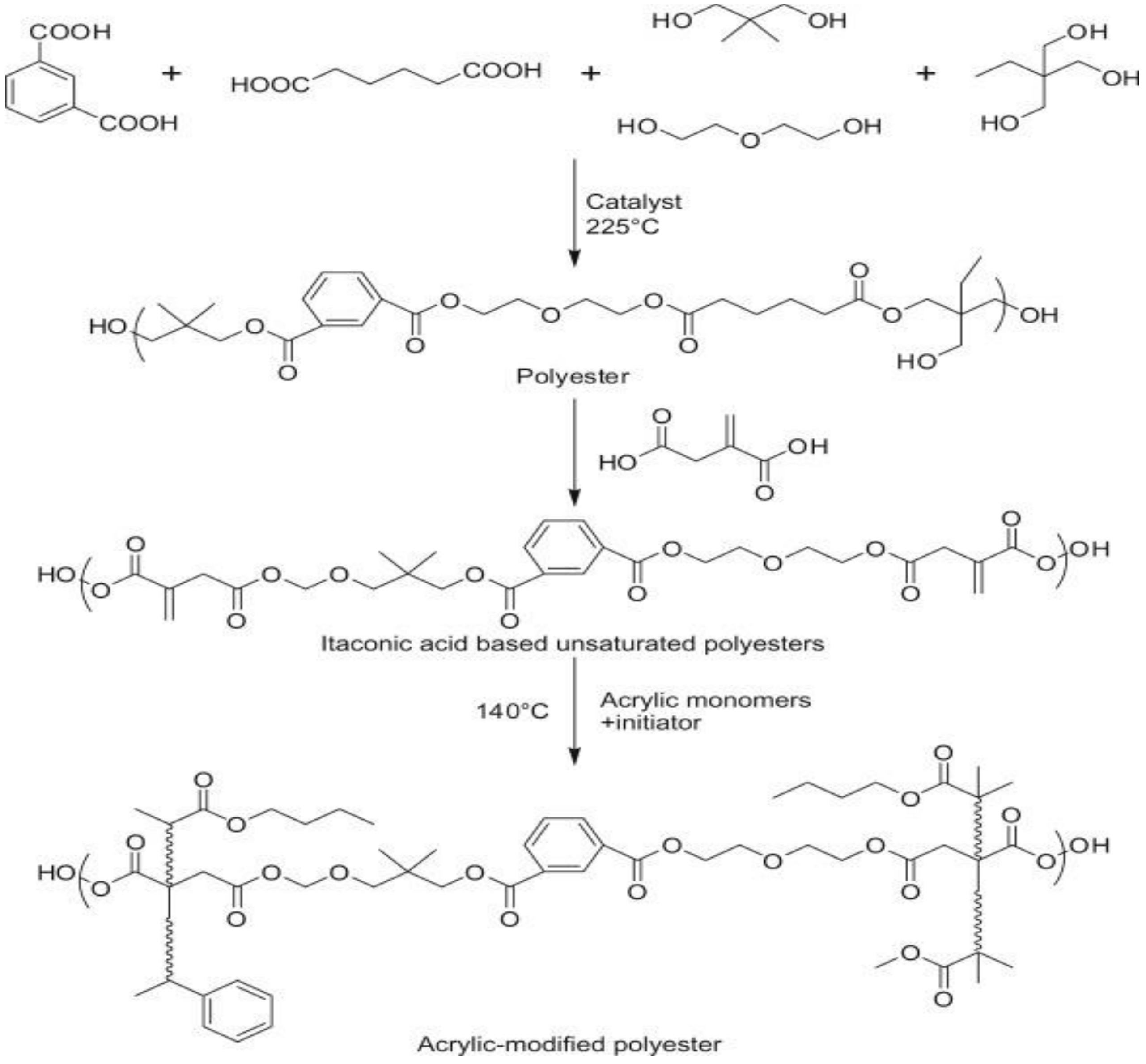


Figure-4 Represent the producers to synthesized Acrylic-modified polyester. Reproduced with permission from Ref. 22

The acrylic monomer enhances the pigment's abrasion resistance, toughness, polish and external stability. It also improves the paint's compatibility with a solvent, preventing the resin from crystallising [22].

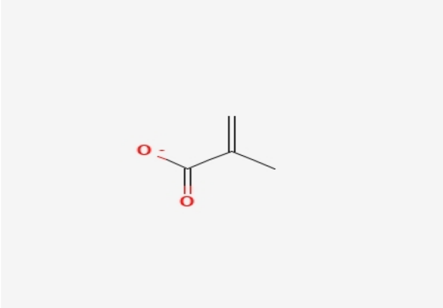
5. Modification of Unsaturated Polyester Resin by Reactive Diluents

5.1 Petroleum-based reactive diluent

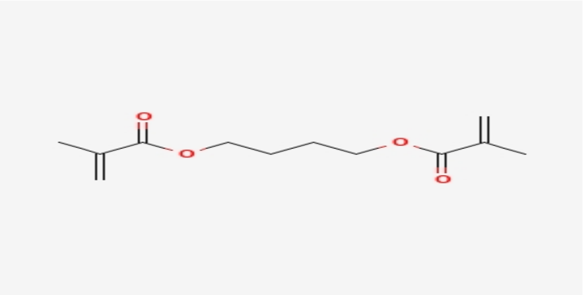
Styrene drastically decreases the viscocity and exhibits good solubilty with unsaturated polyester resin (UPR), which has a longer chain length and higher molecular weight.[23,24] Isophthalic acid, maleic anhydride, neopentyl glycol, and dicyclopentadiene resin were used in the formulation of UPR. Styrene and resin combine to produce a dielectric compound that is applied in electrical applications [25]. Styrene can regulate the thermal shrinkage of UPR, but toxicity, carcinogenicity, and volatility are some of the issue [26,27]. By including suppressants such as polyether, polyether block copolymers in the system, the volatility concern might be overcome. However, the addition of these suppressants increases the system's overall cost [28]. Inks for lithography, screen printing, and wood coatings all frequently use polyester acrylates [29,30]. The acrylic-modified polyester diluents are extremely compatible with a wide range of film-forming polymers. After curing, these coatings showed better resistance to solvents, superior crack resistance, flexibility, lustrous and durable finishes, excellent adherence to the substrate, and superior pigment dispercibility [31,32]. Additionally, co-monomers of acrylate are in charge of controlling of the thermal shrinkage of UPR [26]. Due to their higher reactivity and lower volatility acrylic-modified UPR is favoured over UPR-styrene systems. For instance, butanediol dimethacrylate(BDDMA) and DEGDMA (Diethylene glycol dimethacrylate) are less volatile than styrene and MMA, which are both extremely volatile and evaporate in less than an hour [33,27,34]. Tri(ethylene glycol) divinyl ether (TDE) was used by Wendi Liu et al. as a reactive diluent for UPR. Using polar forces and dispersion forces, it was discovered that the system reduced viscosity and enhanced miscibility [35]. When N-vinyl-2-pyrrolidone (NVP) was used as a reactive diluent, in the process, it was discovered that the NVP-UP resin's bending modulus was larger than UP-Styrene's, despite the fact that its incompatibility and tension strength were equivalent. This is because N-vinyl-2-pyrrolidone contains a nitrogen atom after free-radical polymerization, which increases the polymer's crosslinking density [35].

5.2 Bio-based Reactive Diluents

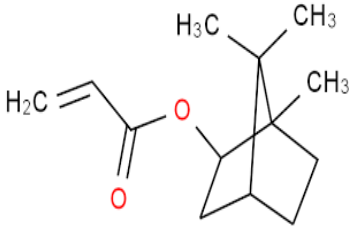
Most commonly used reactive diluents are petroleum-based; Nowadays, work is being done to develop alternative bio-based reactive diluents. Isobornyl methacrylate (IBOMA) and Lauryl methacrylate (LMA), which is derived from fatty acids, were examined for their behaviour as reactive diluents by Sylvain Cousinet et al [34]. Acrylated epoxidized soybean oil(AESO) has the potential to replace acrylates and styrene.Maflda S. Lima et al. additionally examined at the influence of the reactive diluting agents sobrerol acrylate (SobAcr) and sobrerol methacrylate (SobMet) on UP resin [35,36]. By giving novel bio-based Furoic acid glycidyl methacrylate (FAGM), a thermosetting resin with outstanding mechanical qualities, was synthesized by Sadler et al. using furoic acid and glycidyl methacrylate as a reactive diluent [37]. Cousinet et al. evaluated three bio-based methacrylates as possible styrene alternatives, including butanediol methacrylate (BDDMA), isobornyl methacrylate (IBOMA), and lauryl methacrylate (LMA) [34]. Figure-5 shows some examples of bio-based reactive diluents.



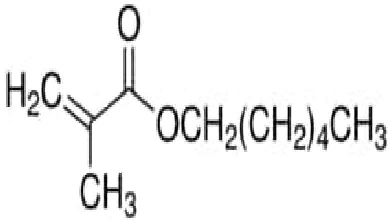
Methaacrylate



Butanediol-dimethacrylate



Isobornyl methacrylate



Lauryl methacrylate

5.3 Ionic liquid-based Reactive Diluents

Ionic liquids (ILS) have shown promise as environmentally friendly polymerization solvents because of their low volatility and chemical stabilities. PILs used as a reactive diluent in UPRs, will replace styrene in a less volatile method and add functionality (such as ionic conductivity, hydrophobicity, and thermal stability) to `cure UPR networks [38]. Non-volatile ionic liquid reactive diluent for UPRs when combined with the non-reactive diluent dimethoxymethane, yield resins appropriate for Vat- photo polymerization. By using industrially applicable procedures for the UPE synthesis and a PIL reactive diluent to enable VP processing, low-volatility UPR. The photo-cured UPR structure possible to print high-resolution 3D structures. Figure-6 Represent the synthesis of UPE Oligomers A and the subsequent photo-curing of UPE oligomers B with phosphonium PIL reactive diluents [39].

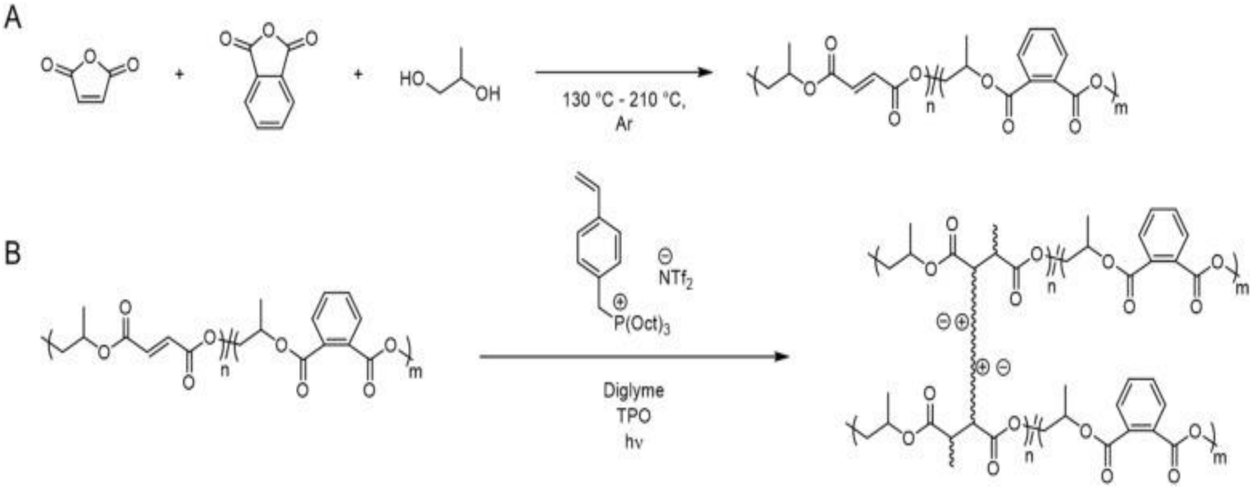


Figure-6 Represent the synthesis of UPE Oligomers A and subsequent photo-curing of UPE oligomers B with phosphonium PIL reactive diluents. Reproduced with permission from Ref. 39

6. Modification of Composites by Properties-

The fibre-reinforced plastic (FRP) industry as well as multiple decorative coatings frequently used thermosetting UPEs. These resins are widely used because of their inexpensive cost, ease of processing, ability to be blended with reinforcements, efficient room-temperature curing without volatile by-products, remarkable dimensional stability and the large range of grades available. Due to its superior chemical resistance, ease of fabrication, high strength-to-weight ratio, and flexibility in product design, FRP is employed in a wide range of engineering applications [40]. Non-reinforced cross-linked UPRs are used in the automotive, aviation, electronics, construction, and packaging industries as structural materials (such as cultured marble and solid-surface countertops), adhesives, coatings, or insulating materials [41,42]. In contrast, UP composite matrices have an extended record of application in a number of innovative domains, including the construction of structures, waterlines, the underwater and terrestrial transport industries and naval structures [43]. UPE/organo-clay nano-composites were used to study chemical resistance. According to the results, clay content increased drastically with an increase in mechanical abilities, including tensile and flexural properties. These polymer clay composites may have strong mechanical and thermal resistance to non-aqueous solvents. The mechanical properties and thermal resistance of thermosetting resins can often be improved by clays [44]. The flammability and production of hazardous gases under the fire of polymeric material is an essential drawback. Tabatabai et al. used unsaturated polyester resin with gypsum from flue-gas decomposition (FGD) to solve this issue. The thermal and mechanical results showed that adding up to 50% FGD gypsum might improve the natural mechanical properties of polyester resin. Results from a thermo gravimetric study (TGA) revealed a notable improvement in mass retention inversely related to gypsum concentration. FGD gypsum created a protective physical barrier on the resin's outer surfaces during an intense fire. FGD gypsum has the potential to be an advantageous and affordable fire-resistant addition to polymers [45]. In the research conducted by Doan et al. [46], the major objective was the potential of water stone powder as a filler in composite materials with a UP matrix. Stone silvers and stone-cutting muck were produced as these wastes. The preparation of UPR composites including various stone powder fillers. Researchers have looked and examined how, the type of powder affected the composite's mechanical properties, water resistance, thermal stability and surface fracture morphologies. After adding the "waste" filler, the composites' moduli increased by 100% and their hardness increased by 80% resulting in a more cost-effective material and a contribution to waste reduction. Jiang et al. treated carbon fibres using monofunctional (methacryloIsobutyl) and multifunctional (methacrylate) polyhedral oligomeric silsesquioxanes (POSS), then combined these with unsaturated polyester resin to develop composites. They exhibited significantly higher interfacial sher strength (IFSS) and lamellar strength (62 and 67 MPa, an increase of 31.9% and 42.6%, respectively). In addition, modified Carbon fiber (CF) composites had larger impact energy than CF/UPR composites [47,48]. Powdered coconut and snail shells (5% and 50% , respectively) were added to UPR. While the composites made of snail shells had higher thermal properties, the coconut shell particles improved the tensile qualities. The composites' greatest increase in tensile elongation was 375%, while their increase in micro-hardness was 125% over virgin UPR. The composites highest increase in tensile strength over virgin UPR was 140%[49,50]. Fly ash that has been absorbed and surface-treated particles used as fillers to create composites with unsaturated polyester resin. Both show improvents in mechanical properties, while surface-treated fly ash composites performed better in some areas [51]. Composites of unsaturated polyester resin filled with nano and micro-sized silica, nano-ZnO, and chitin powder showed improved tensile and solvent resistance. Hardness increased when silica and ZnO were added, however , it reduced when chitin was included [52]. UPR was filled with waste material called expanded polystyrene (EPS). Different amounts (02 weight per cent) of tin and zinc oxides were added. The composite materials were created as glazing or flat panel windows to replace the glass. Results showed that each addition responded differently with the polymeric matrix, both EPS and metal oxide provided better flame retardancy to the composites [53]. Baskaran et al. developed UP nano composites by casting nano alumina (6070 nm, 19 wt%)

into them. The greatest increase in storage modulus was 5 wt% filler loading level with char yieds rising in proportion to alumina concentration in the composites, the thermal stability of the nano-composites was similarly higher [54]. Improvements in thermal characteristics were seen in UP-Polyhedral oligomeric silsesquioxane(POSS) hybrid nano-composites proportional to the amount of functionalized POSS added [55]. Hassan et al. looked into the possibilities of creating nano-composites with outstanding flame retardancy, thermal stability and mechanical qualities utilizing a UP/Phenolic/MMT (montmorillonite) blending system filed with ammonium polyphosphate (APP). [56] According to Romanzini et al. modifying the chemical composition of Montmorillonite (MMY) (Cloisite) with compatible silanes, such as vinyltriethoxysilane and methacrylic propyltrimethoxysilane, reduces the likehood of dispersion and enhances the conection between MMT and UPR improving the materials thermally mechanical motion and combustion retardancy [57]. The largest weight gain/loss with increasing clay content is observed in the chemical resistance of organically modified MMT-UPR composites under aqueous conditions in acetic acid, sodium carbonate. UPR-MMT filled nanocomposites solvent resistance was investigated in acetic acid utilizing the equilibrium swelling method. Low diffusion coefficients were visible in the composites. For all the samples, temperature increases resulted in higher diffusion, absorption and penetration coefficients [58]. The crystallinity index of the cellulose nanocrystals (CNCs) was lowered after surface treatment as demonstrated by nanocomposites of UPR and CNCs created by Kargarzadeh et al. The size and aspect ratio of the rod-like nanoparticles, however were unaffected. In the presence of silane treated CNCs (STCNCs) the tensile strength and stiffness of the composites increased. It’s interesting to note that the inclusion of untreated CNCs greatly increased the impact of energy. Improvements were made to the viscoelastic behaviour and thermal deterioration of the CNC and STCNC reinforced nanocomposite. After CNCs were added it was discovered that the UPR water absorption behaviour decreased [59].The main issues preventing the wide spread use of glass fiber reinforced unsaturated resin (GUPR) composites are their poor interfacial property and low flame- retardant efficiency. Zhang et al. effectively solved these problems by grafting modified silane combination proxies into the surface of the glass fibers and including a multi-element fusion fire-retarder in the structure of the glass fiber. The interface modifiers for phosphours containing flame retardants (PKH-550) and sulfer containing flame retardants (PCH_3-S) were created and PKH-550 was effectively grafted onto glass fiber. Figure-7 Show a schematic diagram of the surface modification of glass fiber using PHK-550 [60].

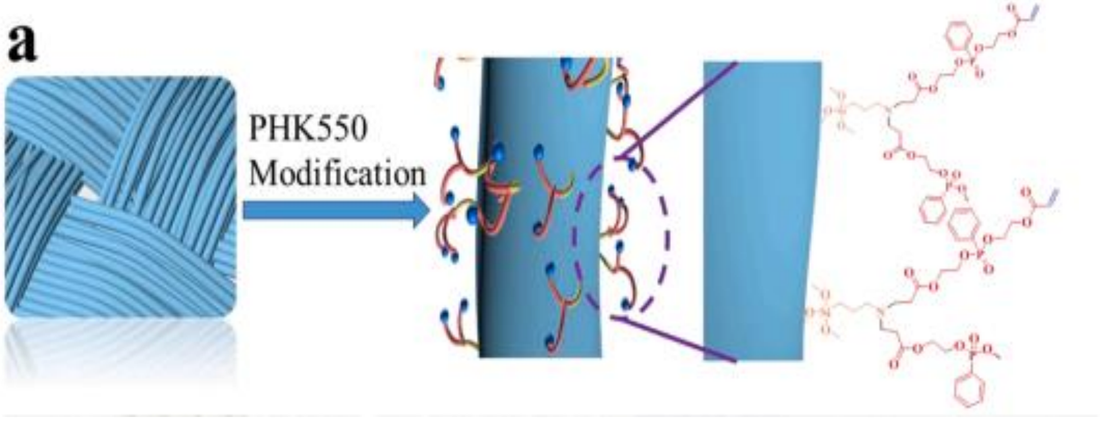


Figure-7 Schematic diagram of surface modification of glass fiber. Reproduced with permission from Ref. 60

Tests on unique and modified glass fibers surface contact angles. The findings indicate that while the contact angle of modified glass fiber decreased to 94° from 116° for unmodified glass fiber. It is clear that the modified glass fibers surface features were altered to improve the wetting effect of the unsaturated polyester resin. The application of PCH_3-S flame retardants can greatly increase the fire safety performance of GUPR composites. The flame retardant qualities of GUPR composites gradually increased with an increase in PCH_3-S flame retardant applied increased this was due to the flame retardants poor dispersion in the matrix. Before employing PKH550 to modify the glass fiber, the glass fiber was treated by the plasma method to lessen the effects of the absorbing method and the fire extinguisher application on the structural features of the blended material [61,62]. According to the findings GUPR composites have achieved substantially greater tensile strength. The tensile strength of P-PGF/UPR (Plasma-Pure Glass Fiber/UPR) modified after plasma treatment of glass fiber increased to 319.27 MPa from the 296.93 MPa tensile strength of PGF/UPR (Pure Glass Fiber/UPR).Even with the addion of 20 wt% flammable to the matrix, the tensile forces of P-MGF/UPR (Plasma modified glass fiber) 20% considerably superior to composite materials produced without the use of plasma innovation by 42.33% and 58.40% respectively. According to the above results, the plasma treatment method may considerably reduce the damage that the immersion method and the inefficient spreading of the flammable additive produce to the structural integrityof the combined material.. The tensile strength of P-MGF (modified glass fiber)/UPR 20% exhibited an important increase over P-PGF(Pure glass fiber)/UPR 20%. This revealed that using the plasma technique combined with PKH550 helped to enhance the mechanical properties of the GUPR composite as well as the interfacial compatibility between the glass fiber and matrix. Figure:8 show that tensile strength of GUPR composites.

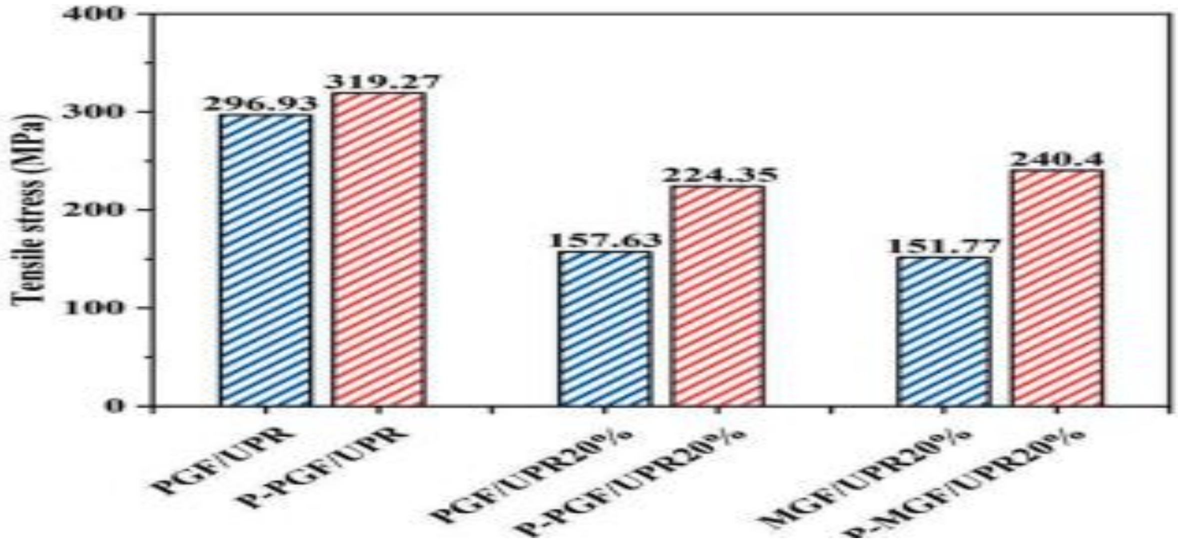


Figure:8 Tensile strength of GUPR composites. Reproduced with permission from Ref. 60

The Solid-phase and gas-phase flame retardant mechanisms of PKH550 and PCH_3-S were responsible for the improvement in the fire safety performance of MGF/UPR 17.5% composites. The exact measurement was precise as follows: Phosphoric acid, pyrophosphoric acid, silicon-containing compounds in the condensed phase and phosphorus-containg gaseous form chemicals were produced as a result of the burning of PKH550. At the same time, the silicon- containing molecule in the reduced stage suppoted the stability of the carbon-based layer. The process of ignition can be successfully stopped at stable temperature of carbon based layer, which can stop the transfer of the surroundings,flammable gas products and thermal insulation. Compounds in the gas phase that contain phosphorus can lower H and OH free radicals by free radical elimination processes having the effect of putting out a flame. In the case of PCH_3-S in addition to phosphoric and pyrophosphoric acids the condensed phase products of PCH_3-S includes SO_2 in addition to phosphorus containing molecules. In addition to reducing the amount of fuel needed to maintain combustion by diluting the flammable pyrolysis gas by products. SO_2 also helped to trap free radicals. The schematic diagram of the flame retardant mechanism of MGF/UPR 17.5% composite was shown in figure 9.

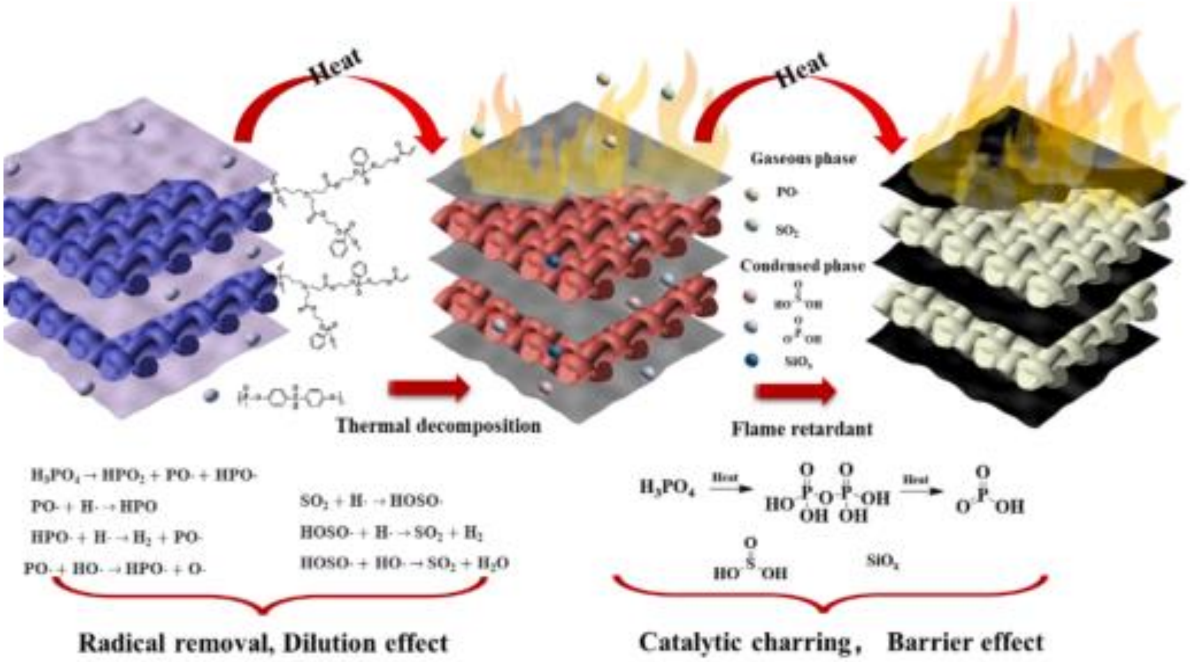


Figure-9. Schematic diagram of the flame retardant mechanism of MGF/UPR 17.5% composite. Reproduced with permission from Ref. 60

The mechanical properties of composites made of unsaturated polyester resin and Microcrystalline Cellulose (MCC) that have been surface modified with methacrylic anhydride were improved. MCC modification reduced intermolecular hydrogen bond interactions between the carbonyl group of the matrix (polyester) and the hydroxyl groups of the filler. Modification decreased the friction between the matrix and the filler, which impacted the stiffness of the composites [50,[63]]. According to Pereira et al. investigation into the fire-resistat effects of layered double hydroxides (LDHs) such as adipate-LDH (A-LDH) and 2-methyl-2-propane-1-sulfonate-LDH (S-LDH), when added to unsaturated polyester resin revealed that by adding 1 wt% of A-LDH, the UPR combustible was drastically decreased (by 46% and 32%) [50,[64]]. Recently, the authors developed bio-based internal GFRP (Glass Fiber Reinforced Polymer) composite using vacuum infusion to combine glass fibers and a high performance bio-based unsaturated polyester resin [[65]]. Abu T. al. assessed a novel high-performance bio-based unsaturated polyester resin that was manufactured internally utilizing raw ingredients generated from renewable sources and was used to create a GFRP composite via vacuum infusion. The results of mechanical characterization tests demonstrated that the mechanical properties of the bio-based GFRP composite compression in –plane shear and interliner shear were equal to or even better than those of its petroleum-derived equivaent, demonstrating the biodegradble resins capacity to saturate glass fiber strengthening and finish sufficient fiber-matrix bond in the dried invention. Although the glass transition temperature of the bio-based GFRP composite was slightly lower than that of its conventional equivalent in terms of thermo-mechanical behaviour, it still met the threshold of 60 °C, allowing for its usage in structural building applications [[66]].

Conclusion

In this paper, we reviewed various modifications in the field of unsaturated polyester, such as modification in the synthesis of an unsaturated polyester resin, the reactive diluent of an unsaturated polyester resin and the properties of composites, which will be improved by changing structure, bio-based components, ionic liquid, inorganic fillers, natural and synthetic fibers. Reviewing the modification of unsaturated polyester resin leads to the conclusion that modified unsaturated polyester resin has a wide range of application, including coatings, marine, aerospace industry, construction and bio-based applications. Due to their excellent properties like high performance, thermal stability, mechanical and flame retardants. Unsaturated Polyester Resin has an excellent scope in future.

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Who voluntarily contributed to this study.

Declaration

The author declares no conflict of interest.

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