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Chemical modification of raw *Quercus leucotricophora* wood strips and studies of its physicochemical properties and antifungal behavior

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ABSTRACT

Modification of *Quercus leucotricophora* (Ql-raw) wood strips has been carried out by its grafting with acrylamide and methylmeth acrylate using CAN-HNO_3 redox initiator system. Various reaction parameters such as time, pH, initiator, monomer concentration and temperature were optimized to attain the maximum percentage of grafting. 62% of maximum grafting was observed at these optimized parameters. The physiochemical properties of raw Ql-raw and grafted *Quercus leucotricophora* (Ql-g-poly(AA-co-MMA)) wood strips were studied in detail i.e., swelling behavior in diverse polar and non-polar solvents and resistance to acid and base attack. The antifungal behavior of Ql-raw and Ql-g-poly(AA-co-MMA) was also investigated. Ql-g-poly(AA-co-MMA) wood showed resistance toward acid and base attack as compare with the Ql-raw. The Ql-raw and Ql-g-poly(AA-co-MMA) wood were characterized by employing instrumental techniques such as Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM) and X-ray diffraction (XRD). The SEM micrographs display the variance in surface morphology of Ql-raw and Ql-g-poly(AA-co-MMA) wood strips.

Keywords: *Quercus leucotricophora*, Acryl amide, Methyl meth acrylate, Grafting

1. Introduction

The wood has a fibrous nature that has made it one of the most suitable and adaptable raw materials for a variety of uses. The 3-D biopolymer complex-composite composed of cellulose, lignin and hemicellulose is stable and retains its property for long periods. Physical degradation occurs at the microstructure level due to presence of chemically reactive sites. These types of degradations are accelerated by UV radiation associated with sunlight. The hydroxyl groups present adsorbs water from moist atmospheres which move into the wood matrix. The adsorbed water is apprehended by hydrogen bonding, wood moisture changes are affected by humid surroundings result in shrinkage and tenderness of wood and results in its physical deprivation, and occasionally leading to its mechanical failure. Cellular structure of wood is designed by nature so that it become as strong as steel on weight basis. During years of development, ways have been

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found to make wood more stable, harder and stronger for specific needs, and also a substitute of steel and other costly materials which are not environmental friendly [1,2]. Not only the wood but also plant fibers, gums and biopolymers have extensively researched for their properties and composites materials obtained from them [3–5]. Wood components are degraded by microorganisms, insects, termites, and marine animals which attack wood for food and shelter. Wood preservation techniques were adopted to protect wood against such biological degradation as well. Similarly, chemical treatments have been applied to reduce the combustibility of wood. In recent years, studies have been focused for chemical modification of wood to enhance its behavior when used in adverse environmental conditions. Some similar studies have been extended to wood chips and fibers to manufacture improved composites such as flake boards, fiber boards, particle boards, etc. [1]. This report, however, limits itself to chemical modification of solid wood only. Reactive extrusion was used as suitable method for the alteration of wood, with maleated polyolefins [6].

On the earth cellulose is the one off plentiful polymer which owns several unique physicochemical properties such as biocompatibility, fine CS(cross-section), durability, heat stability and great mechanical properties. Cellulose displays better chemical reactivity due to the existence of 3-hydroxyl groups in the entire glucose residue [7].

Despite of presence of attractive properties, cellulose also possess some limitations, which are deficiency in thermoplasticity and extraordinary hydrophilicity, to overwhelm these shortcomings, chemical alteration of the cellulose structure is compulsory. Cellulose modification by graft copolymerization amends its chemical and physical behavior; in addition there is increase in its functionality. In case of graft copolymerization, free-radical polymerization has recognized more attention due to several attractive features such as it can be applied for a variety of monomers, capability to deliver limitless number of co-polymers and forbearance to water [7]. The free radical polymerization involves the formation of reactive sites on the substrate followed by addition of monomer and propagation of reaction [8–12]. Free radicals are formed at cellulose backbone by oxidation by means of various initiators. Ce(IV) ions has attained more significance because of its simplicity of application and high grafting yield as matched to other redox systems i.e., Fe(II) [13]. Grafting of methyl meth acrylate (MMA) on cellulose materials, such as bamboo [14], and fibres of *Grewia optiva* by the use of different redox systems has been notified. Optimization of different parameters were studied in the graft copolymerization process such as, effect of varying temperature and time, as well as the monomer concentration, initiator, HNO_3 etc [15].

A wide range of monomers like ethylene, propylene, vinyl chloride, acrylonitrile, methyl meth acrylate, acrylamide and styrene are available that yield polymers with a diverse properties, ranging from soft rubber to brittle solid products [16–20]. The various hydrogels were prepared using these monomers and used for numerous applications such as wound healing, drug delivery adsorption etc [18,19,21–24]. These composites such formed are commercially known as wood-plastic composites (WPC).

Chemical modification processes have opened many new facets for better utilization of the wood resource. The current exploitation is, however, limited to a few uses where the unique properties of the end product justify the added high costs. Manufacture of compressed wood products, resin-impregnated densified laminates, and wood-plastic composites is fairly well established in many countries around the world including the developing countries [25,26]. These products are now produced to manufacture a wide variety of machinery parts and articles such as bobbins and shuttles for textile and jute mills, silverware handles, desk legs, door handles, bearings, rollers, die mould patterns in the automobile industry, panels for electrical equipment, master shoe lasts, acid tanks, etc. Compregnated wood has recognized for a enormous number of industrial applications [26].

Cell-wall modification studies have received the greatest attention during the past few years, and many reactions such as acetylation, epoxide formation, etc., yielding enhanced wood properties have shown technical feasibility. Immediate application of the technology appears feasible for treatment of surface veneers for high quality panels as some treatments such as acetylation, while not interfering with gluing, have been found to slow down surface deterioration due to checking and discoloration [27]. Chemical modification also offers possibility of bonding fire-retardant chemicals such as organo-phosphorus monomers by in situ polymerization or by cell-wall reactions [2].

In present study, the raw wood of *Quercus* has been modified using facile chemical grafting method to achieve better physicochemical properties. Acrylamide and methylmeth acrylate have been used as monomer. The comparison between raw and grafted *Quercus* wood properties was studied. The antifungal behavior of modified *Quercus* wood was investigated in detail.

2. Experimental

2.1. Materials

Quercus wood strips gather from nearby region of Shoolini University, Bajhol (Solan) Himachal Pradesh. Wooden strips kept under room temperature for 2–3 days and dipped into water for 1 day at room temperature. Wooden strips then taken out and dried at room temperature. Its outer surface is activated so that can be used for further reaction steps. Different chemicals used are, acryl amide (AA), ammonium ceric nitrate (CAN), methanol, acetone, benzene, methyl meth acrylate (MMA) and nitric acid (NA) obtained from Sigma Aldrich and were of analytical grade.

2.2. Pre-experimental conditions

The raw *Quercus* wood strips were pretreated to remove dirt, gums and mucilage from wood. For this the wood strips of *Quercus* are cut in the size of 200 × 20 × 2 mm (longitudinal × tangential × radial). The wooden strips were dipped into the water for one day and dried at room temperature for 24 h, then exposed to solvent extraction (mixture of benzene/acetone/methanol: 4:1:1 by volume/volume ratio) in soxhlet for 8 h. Finally, the strips were then dried at 105°C for 5 h, moved to desiccators to cool to room temperature and weigh on the balance scale [28].

2.3. Optimization of different reaction parameters

2.3.1. Temperature optimization

The grafting is carried out at different temperature i.e. 35°C, 45°C, 55°C, 65°C and 75°C on Ql-raw wood with MMA and AA monomers. The percent grafting yield was calculated, to find out optimum reaction temperature.

2.3.2. Time optimization

The reaction time was varied as 1–5 h. Grafting was carried out at this different count of time on Ql-raw wood with MMA and AA monomers. The % grafting yield was calculated, to find out optimum time for the reaction.

2.3.3. Initiator optimization

The grafting was carried out at different concentration of initiator (CAN) i.e. 5%, 7%, 12%, 15% and 20% on Ql-raw wood strips with MMA and AA at 65°C temperature. The percent grafting yield is calculated, to find out optimum initiator concentration.

2.3.4. Monomer optimization

Grafting was carried at different concentration of monomers of AA and MMA in the given ratio:-(1) 0.1M (molar) AA, 0.2M MMA, (2) 0.2 M AA, 0.1M MMA, (3) 0.2 M AA, 0.2M MMA, (4) 1.5 M AA, 0.05M MMA and (5) 0.05M AA, 1.5M MMA on Ql-raw wood at 65°C for 2 h. The percent grafting yield was calculated, to find out optimum monomers concentration.

2.3.5. Optimization of pH

Grafting was carried out at different pH i.e. 2, 5, 7, 9 and 14 on Ql-raw wood strips with the monomers of AA and MMA for 2 h at 65°C temperature. To find out optimum pH for grafting the percentage grafting yield was calculated at different pH. Percent graft yield (grafting %) of grafted *Quercus* wood was considered by using following formula [13]:

$$\% \text{ Grafting} = \frac{W_g - W}{W} \times 100 \tag{1}$$

where W_g is the weight of the Ql-g-poly(AA-co-MMA) strips and W is the weight of the Ql-raw strips.

2.4. Physiochemical behavior of Ql-Raw and Ql-g-poly(AA-co-MMA) wood strips

2.4.1. Swelling behavior

Swelling nature of Ql-raw and Ql-g-pol(AA-co-MMA) wood strips in different solvent systems was studied. For this purpose the samples of Ql-raw and Ql-g-poly(AA-co-MMA) wood strips were suspended in 100 mL of acid, base, water and chloroform. To investigate their swelling nature the strips were weight at different time intervals i.e. 30, 60, 120, 180, 240, 300, 360, 420, 1,440, and 2,880 min. The superfluous of the solvent was removed by pressing tenderly the wood samples in the folds of the filter paper. The final weights of wood strips were recorded. Percentage of swelling (%, S) was considered as follow [29]:

$$\% \text{ Swelling} = \frac{W_f - W_i}{W_i} \times 100 \tag{2}$$

where W_f is the final weight of wood strips and W_i is the initial weight of wood strips.

2.4.2. Chemical resistance

Chemical resistance studies of Ql-raw and Ql-g-poly(AA-co-MMA) samples were calculated by dipping the known weight of Ql-raw and Ql-g-poly(AA-co-MMA) samples in 1N NaOH, 5N NaOH, 1N HNO_3 and 5N HNO_3 for different time interval i.e. 30, 60, 120, 180, 240, 300, 360, 420, 1,440, and 2,880 min. Then samples were taken out after each interval and weight of samples were noted after removing of excess of solution by gently pressing them in the fold of filter paper. Percent weight loss was considered as follows:

$$\% \text{ Weight loss} = \frac{W_1 - W_2}{W_1} \times 100 \tag{3}$$

where W_1 is the the initial weight of the wood strips sample and W_2 is the final weight of the wood strips, respectively.

2.5. Characterization techniques

2.5.1. Fourier transform infra-red spectroscopy (FTIR)

FTIR spectra of Ql-raw and Ql-g-poly(AA-co-MMA) strips were observed and recorded by Perkin Elmer, Spectrum 400, FT-IR spectrophotometer. FTIR spectra of the Ql-raw and Ql-g-poly(AA-co-MMA) were obtained in range of 500–4,000 cm^{-1}. FTIR spectrophotometer was used to identify the structure, composition and the absorption spectra intensity associated with molecular composition of the functional chemical group present.

2.5.2. Scanning electron microscopy (SEM)

Surface morphologies of the Ql-raw and Ql-g-poly (AA-co-MMA) wood strips were investigated with the assistance of scanning electron microscopy (SEM). SEM studies were made on SEM Quant-250. Before focusing electron beam of Model number-09393 (FEI make) the wood samples were gold sputtered to make them conducting [30,31]. SEM micrographs were obtained at different magnifications.

2.5.3. X-ray diffraction (XRD)

X-ray diffraction (XRD) method was performed for phase identification of a crystalline material. The XRD patterns of Ql-raw and Ql-g-poly(AA-co-MMA) were investigated. For analysis samples were finely ground, homogenized, and average bulk composition was obtained. The crystallinity indices (I_c) of Ql-raw and Ql-g-poly(AA-co-MMA) were calculated using the formula [32].

$$I_c = \frac{I_{002} - I_{am}}{I_{002}} \tag{4}$$

where I_{002} is the maximum diffraction intensity and I_{am} is the minimum diffraction intensity.

2.6. Antifungal activity

The PDA media has been used for fungus growth as *Fusarium oxysporum* colonize best in PDA media at temperature i.e., 28°C and pH range 4.5–6.0. *F. oxysporum* is a fungus that belongs to Division-Ascomycota and its strains are soil inhabitants that also exist as saprophytes, and degrade lignin and complex carbohydrates associated with wood and soil debris. To find out fungal anti-activity of wood a nutrient media (agar agar) was prepared by taking 20 g dextrose, 20 g of agar-agar, 250 g potatoes in 1000 mL water and four 250 mL flasks were taken. All of them were autoclaved for about 45 min at 121°C.The media was pour into the flasks inside the laminar. Then media was allowed to remain stand for 20 min, finally spreading of *Fusarium* was done on the prepared media and remained as such for 6 days inside incubator for growth at 28°C. After 6 days small wood logs of Ql-raw and Ql-g-poly(AA-co-MMA) samples were placed inside media till fungi degenerate wood logs. Results were notified after per defined time intervals [33].

3. Results and discussions

3.1. Determination of different reaction parameters

To determine the optimum conditions for grafting of AA and MMA monomers onto Ql-Raw wood, various reaction parameters were optimized which includes temperature, reaction pH, reaction time, initiator, and monomer concentration. The initiator generates Ce(IV) ions. The oxidation of Ce(IV) with cellulose of wood at the C2-C3 unit forms wood-Ce(IV) complex. Further this complex disproportionate to form radicals either at C2 or C3. Free radical reacts with monomers which exist in the reaction to initiate the graft copolymerization leading to chain propagation. Finally the chain termination occurs to complete the polymerizations. Scheme 1 demonstrates the proposed mechanism for graft copolymerization.

3.1.1. Effect of monomer

Values of percent grafting yield for the grafting of MMA and AA onto wood cellulose were investigated as function of monomer concentration and results are demonstrated in Fig. 1(a) percent grafting yield found maximum at 0.1M AA and 0.2M MMA concentrations and when there is change in concentrations, decrease in % grafting was observed. The results are presented in Fig. 1(a). This is due to the reason that greater number of radicals reach on the backbone, resulting in higher grafting yield. The other factor which relates to the monomer concentration effect is the fixed number of active sites that wood surface have thus at optimized monomer concentration these sites becomes completely saturated. So if there is further rise in monomer concentration, homopolymerization will dominates the graft copolymerization and leads in decline of graft yield [34].

3.1.2. Effect of reaction temperature

Fig. 1(b) demonstrates temperature influence on % grafting. It was witnessed that, with initial rise in temperature, % graft yield reaches to optimum value at 65°C and decrease with additional rise in reaction temperature. The probable reason is that the kinetic energy of molecule increases with rise in temperature, as a result greater numbers of radicals are formed on wood cellulose backbone at a quicker rate which results in increase % grafting. But further increases in temperature resulted in decreased percent graft yield, the possible reason behind this is increased rate of chain transfer or termination reactions among monomer molecules and the grafted chain is higher as compared with process of grafting.

3.1.3. Effect of initiator

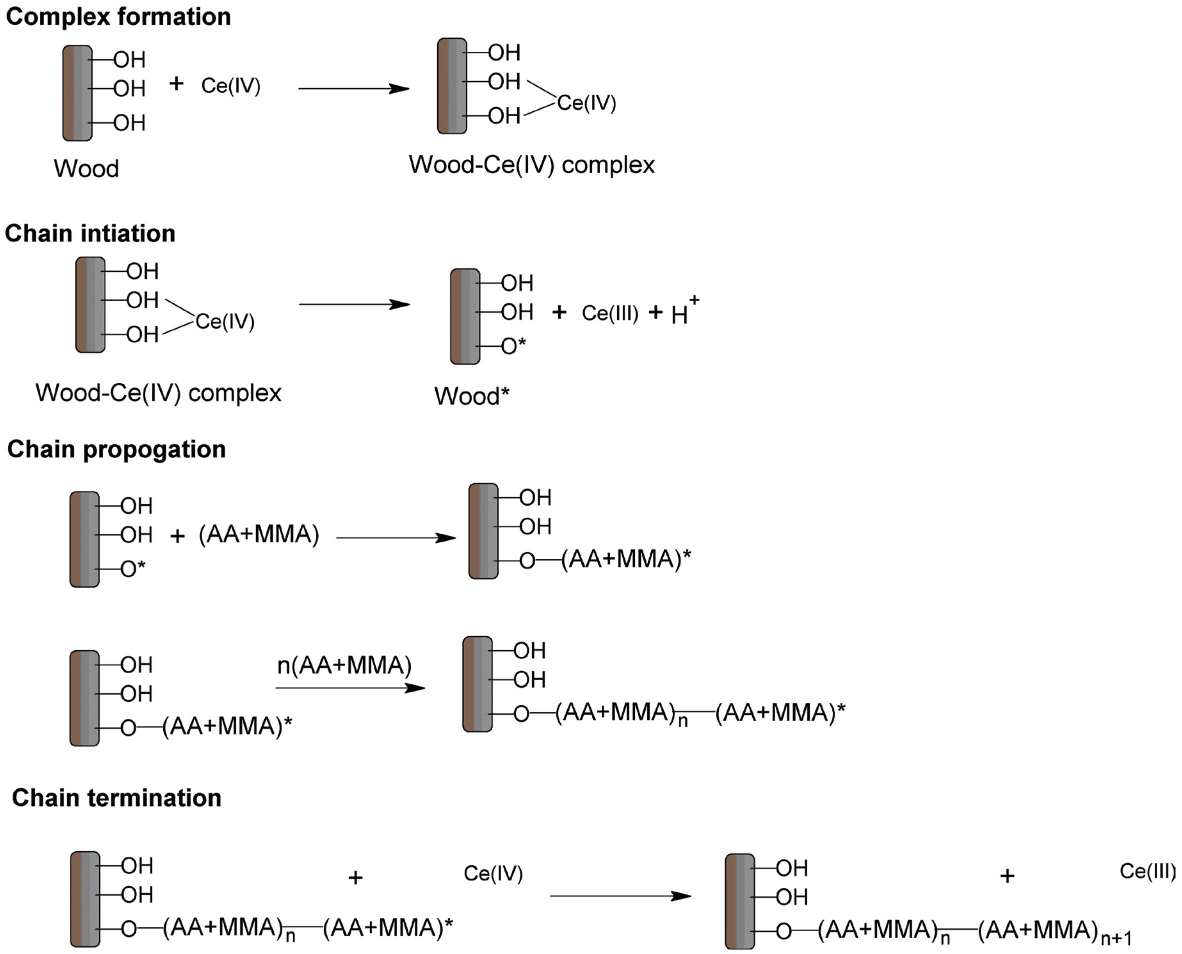
Influence of CAN concentration on % grafting was demonstrated in Fig. 1(c). As revealed from Fig. 1(c), the value of % grafting increases firstly with increase in CAN concentration and becomes optimum at 15%. The increase in % graft yield was due to the creation of more free radical sites on wood cellulose backbone, the probable reason is that there is increase in number of Ce(IV)-cellulose complexes and these complexes decay to produce more active sites. Creation of active sites on to cellulose backbone was followed by MMA and AA graft copolymerisation onto cellulose backbone. Whereas the decrease in % graft yield can be ascribed due to the creation of more Ce(IV)-monomer complexes in place of Ce(IV)-cellulose complexes, which results in the more homopolymer synthesis [35].

3.1.4. Effect of reaction time

Influence of reaction time on % grafting values is demonstrated in Fig. 1(d). As presented in Fig. 1(d), % grafting increases with a rise in reaction time and attain the maximum value at 2 h and decrease afterward. The preliminary increase in % grafting with reaction time can probably explained on the basis of the available more contact time of the monomer molecules i.e. MMA and AA with wood cellulose macro-radical sites during reaction. Beyond this reaction time, homopolymer synthesis and backbiting by active radical because of mutual destruction of the budding polymeric chains predominates, this result in decreased % grafting [20,36].

3.1.5. Effect of pH

Influence of pH on % grafting is presented in Fig. 3(e). The % graft yield remains maximum at pH 2 and further decrease with increase in pH. The ceric ion are present as Ce(IV) and Ce(III) in aqueous solution. The amount of these species varies with the pH of solution. Thus lower pH favors the formation of Ce(IV) ions. The other reason for decrease



Scheme 1. Proposed mechanism for grafting copolymerization of acrylamide and methylmeth acrylate using CAN-HNO_3 redox initiator onto *Quercus leucotricophora* wood.

in % graft yield is probably the premature termination of polymerization reaction when acidity decrease and basicity increase [37,38].

3.2. Swelling studies

Percent swelling of Ql-g-poly(AA-co-MMA) and Ql-raw in different solvents as water, CCl_4, HNO_3 and NaOH were studied and results are demonstrated in Figs. 2(a) and (b). It is observed from Figs. 2(a) and (b) that the percent swelling of Ql-raw wood decreases as water-base-acid-chloroform, and the maximum swelling was seen in water i.e. 77.6%. Higher percentage of swelling in H_2O is anticipated, as water enters into hydrogen bonding with the hydroxyl groups of wood containing of anhydro glucose units. Swelling effect of unlike solvents is based on their structure and dielectric properties. And percent swelling of Ql-g-poly(AA-co-MMA) decreases as chloroform-base-acid-water, and maximum swelling was seen in chloroform i.e. 56.4%. The probable reason behind this is that the MMA and AA block the active sites of the main polymeric backbone which results in this trend of sorption behavior with different solvents. Henceforth, more swelling is witnessed in CCl_4 as equated with the other solvents [39,40].

3.3. Chemical resistivity

The chemical resistivity of Ql-g-poly(AA-co-MMA) and Ql-raw wood was considered in HNO_3 and NaOH solutions of dissimilar concentrations, as demonstrated in Figs. 3(a) and (b). It has been found that the effect of HNO_3 and NaOH on Ql-g-poly(AA-co-MMA) wood strips is less as compare with Ql-raw strips and hence lesser weight loss occurred in Ql-g-poly(AA-co-MMA) as compared with Ql-raw. The maximum degradation for Ql-raw wood was found to be 25.80% in comparison with 8.72% for Ql-g-poly (AA-co-MMA) wood strips in presence of 5N HNO_3. Thus on grafting wood becomes more resistant to the attack of acid and base. This is probably because of the existence of poly(AA-co-MMA) chains on wood strips, which leads to lesser affinity toward acid and base attack on modified wood [39].

3.4. XRD results

Figs. 4(a) and (b) demonstrate the patterns of XRD of Ql-raw and Ql-g-poly(AA-co-MMA) wood, respectively. The Ql-Raw at 2Θ scale presented peaks at 22.06°and 18.05°. Similarly Ql-g-poly(AA-co-MMA) shows peaks at 23.26° and 19.53°. Thus, there is a difference in the peak intensities indicating the deviations in the crystallinity of wood cellulose.

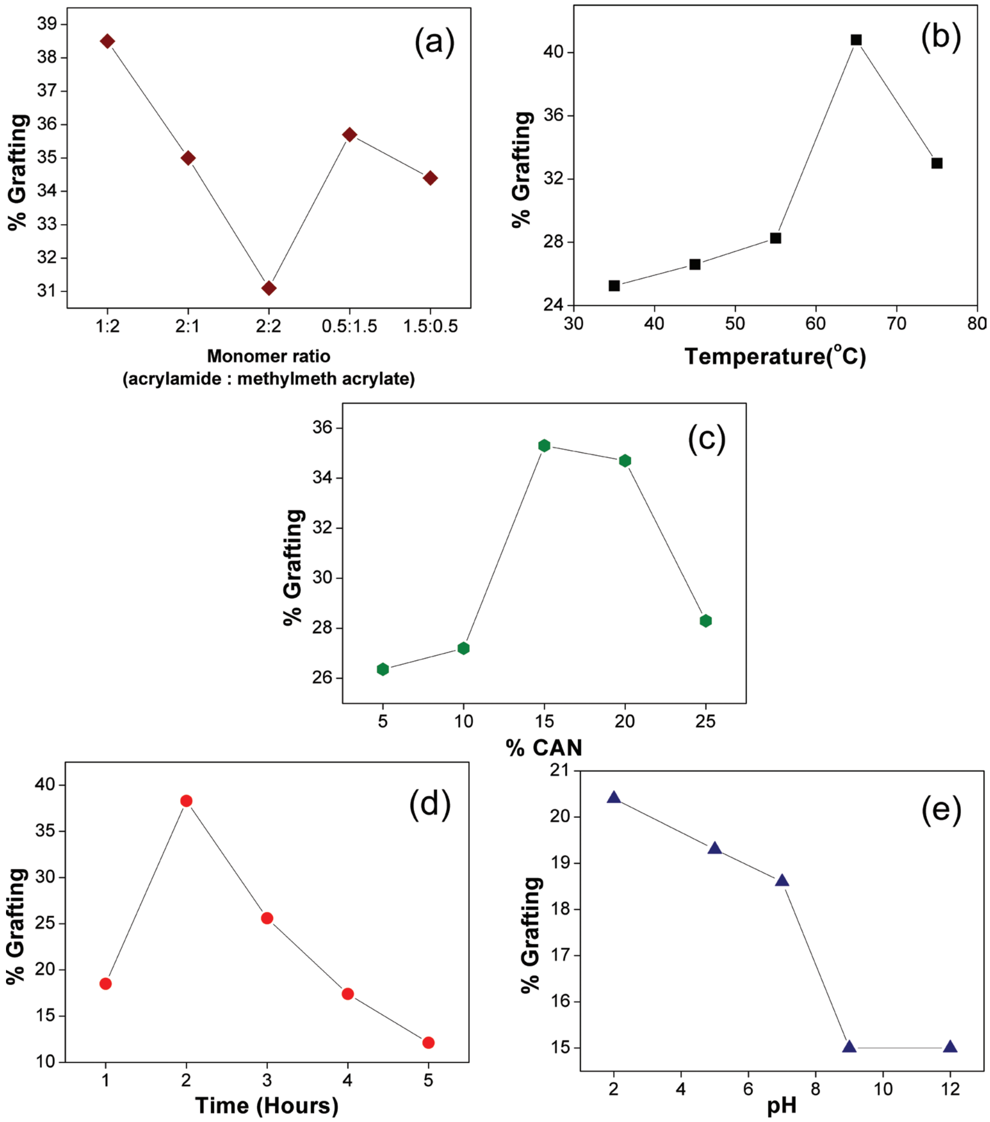


Fig. 1. Optimization of different conditions (a) Monomer (b) Temperature (c) Initiator (d) Time and (e) pH.

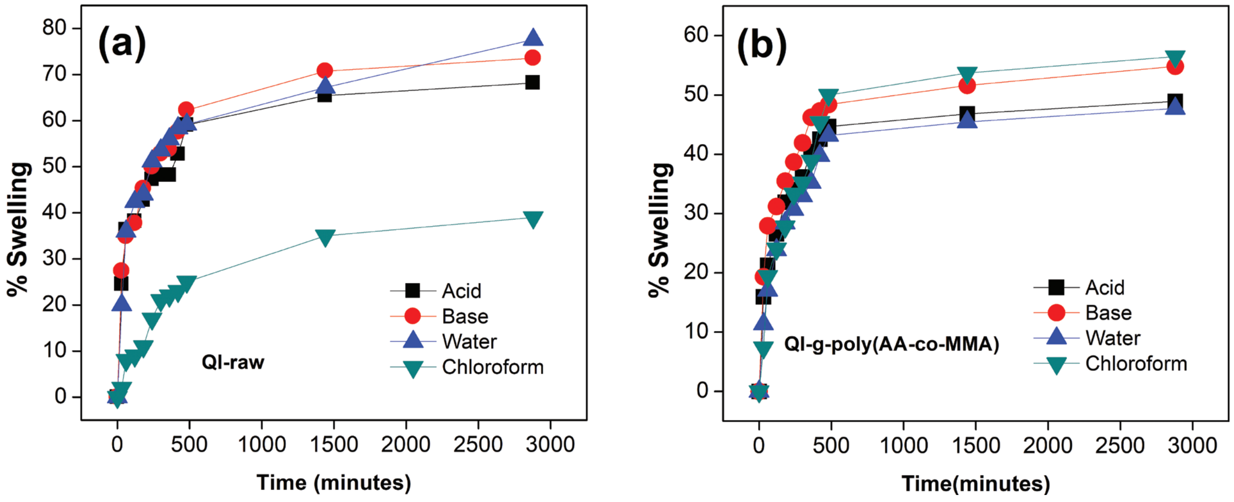


Fig. 2. Swelling studies graphs for (a) Ql-raw and (b) Ql-g-poly(AA-co-MMA).

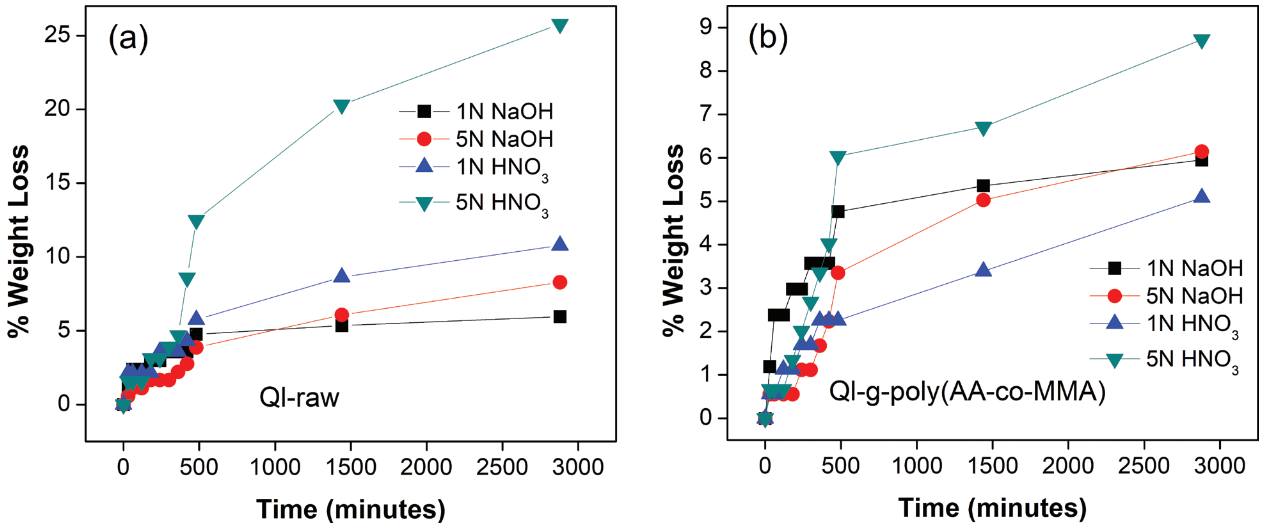


Fig. 3. Chemical resistivity for (a) Ql-raw and (b) Ql-g-poly(AA-co-MMA).

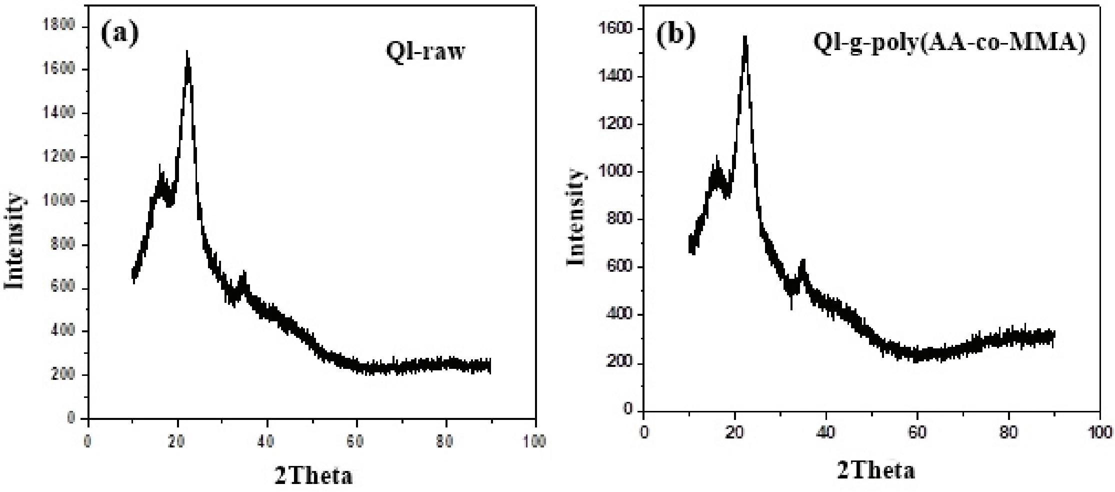


Fig. 4. XRD of wood samples (a) Ql-raw and (b) Ql-g-poly(AA-co-MMA).

The results given in Table 1, displays that upon grafting both percent crystallinity and crystallinity index value reduced. With grafting of AM+MMA onto wood cellulose backbone, there is decrease in the percent crystallinity which specifies a decline in crystallinity of the modified wood and existence of large amorphous region equated to raw wood, this is probably due to the presence of monomer moieties incorporated on wood cellulose backbone [41].

3.5. FTIR results

FTIR spectroscopic analysis of Ql-raw and Ql-g-poly (AA-co-MMA) samples are revealed in Figs. 5(a) and (b). FTIR examination of modified wood display a peak at 3,835.82 cm^{-1} due to –OH stretching and 2,925.86 cm^{-1} probably due to C–H stretching [42,43]. A slight peak at 1,372.84 cm^{-1} shows the existence of C–O group in secondary alcohols and MMA deformation [44]. Also, the broadening of absorbance peak at 1,737.89 and 1,640.87 cm^{-1}, which was ascribed to the C=O group of AA [45]. Amalgamation of MMA onto the cellulose backbone enhanced the hydrophobicity that decreases the amount of absorbed water [46]. A sharp peak at 2,925.86 cm^{-1} indicates the presence C–H symmetrical stretching and presence of MMA. Slight stretching at 1,030.40 cm^{-1} was due to bonded –CH group in plane can be seen in Fig. 5(b). In Fig. 5(b) peak at 1,923.94 cm^{-1}with slight intensity was observed due to MMA. Peak at 2,098.94 cm^{-1} probably due to –OH stretching and 2,143.94 cm^{-1} due to C–H stretching of methyl meth acrylate has been observed.

Table 1
Crystallinity index and % Crystallinity of Ql-Raw and Ql-g-poly(AA-co-MMA) wood

Sample	Crystallinity index	% Crystallinity
Ql-Raw	0.63	62.08
Ql-g-poly(AA-co-MMA)	0.60	61.06

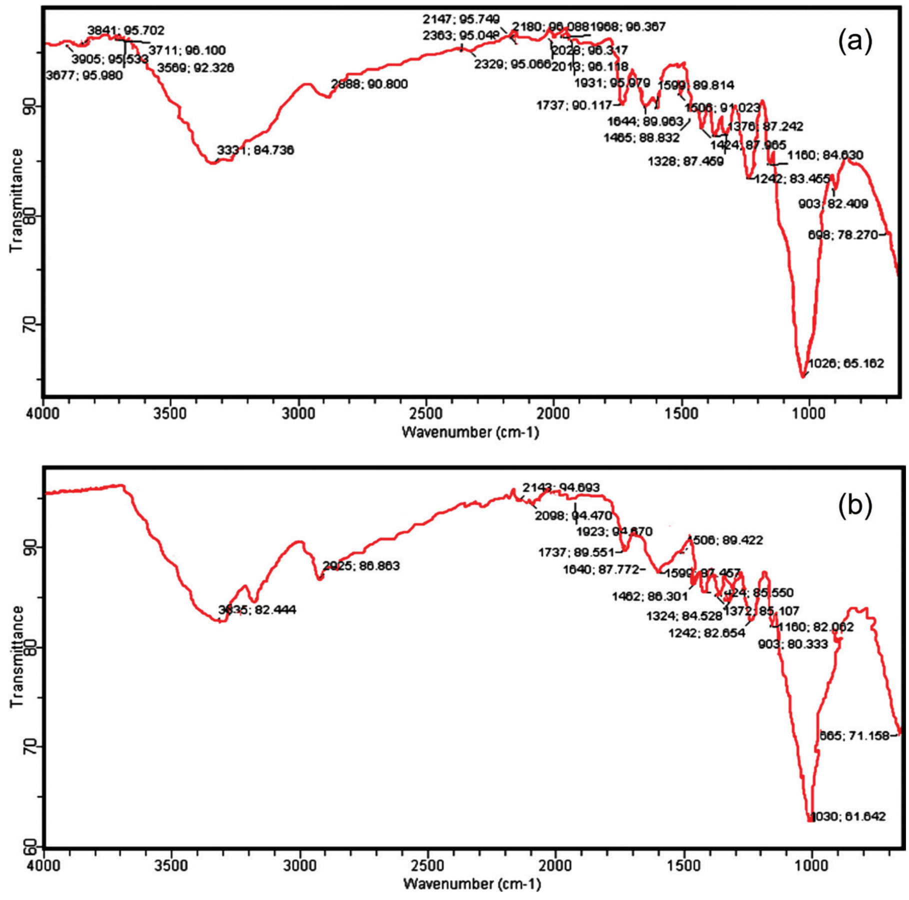


Fig. 5. FTIR of (a) Ql-raw and (b) Ql-g-poly(AA-co-MMA).

3.6. Scanning electron microscopy

The change in morphology and topography of wood surface was considered by SEM. Figs. 6(a) and (b) Ql-raw and 6(c) and (d) Ql-g-poly(AA-co-MMA) reveals clear change in morphologies of raw and modified wood strips. It has been detected that the surface of Ql-g-poly(AA-co-MMA) is extremely rough in contrast with Ql-raw, which is credited to high graft density [47]. As the roughness of surface increases, the adhesion of Ql-g-poly(AA-co-MMA) strips to a monomer matrix was further improved because of rise in the surface area for mechanical interlocking. Thus, it is expected that the rougher surface on grafted wood cellulose improve its adhesion to other polymer matrices and the mechanical properties of material are improved. The changes occur in topology of Ql-raw may be due to incorporation of poly (MMA+AA) chain on wood cellulosic backbone due to which the surface becomes irregular.

3.7. Antifungal activities

The antifungal activity study was done using fungal spreading method, which shows the resistance of Ql-g-poly(AA-co-MMA) wood against the fungi i.e. *F. oxysporum*. In this activity the fungus is grown in the PDA media and then the *Quercus* wood strips were placed in the flask containing fungus. The fungus grows and degrades the Ql-raw wood more rapidly as compare with Ql-g-poly(AA-co-MMA) wood strips. This is due to the resistance of MMA+AA against *F. oxysporum* while there is the growth of the fungus around the Ql-raw, as it can't inhibits the growth of fungus around themselves as no such protective covering is present. Hence, fungus grows easily around the Ql-raw wood strips. Figs. 7 and 8 show fungal (*F. oxysporum*) growth on Ql-raw and Ql-g-poly(AA-co-MMA) wood after 7 and 18 days. The detailed results for fungal growth and percent degradation are shown in Figs. 9 and 10.

4. Conclusion

In the presence of Ce(IV)-ion and nitric acid redox initiator system, the graft copolymerization of AA and MMA from their binary mixture is carried out. To get the maximum grafting yield (62%) different reaction parameters are optimized. Grafting of (AA+ MMA) is confirmed by the FTIR, SEM and XRD which shows structural changes in comparison with raw wood. The desired functionality is obtained by FTIR spectrum of modified wood which shows characteristic peaks at 2,925.86 cm^{-1} due to (–C=H) of MMA.1,640.87 cm^{-1} for C=O group AA. SEM studies show rough surface of the modified wood whereas raw wood has smooth surface morphology. Thus for modification of physico-chemical properties of the Ql-raw wood, graft

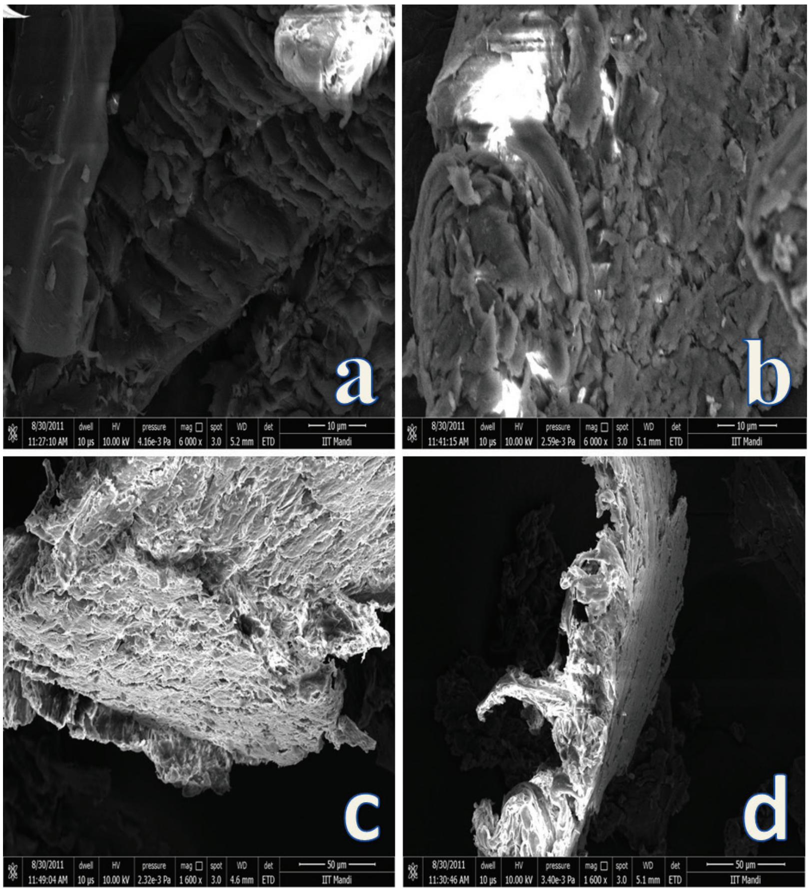


Fig. 6. SEM micrographs of (a) and (b) Ql-raw, (c) and (d) Ql-g-poly(AA-co-MMA).

Fig. 7. Fungal (*Fusarium oxysporum*) growth on Ql-raw and Ql-g-poly(AA-co-MMA) wood after 7 d.

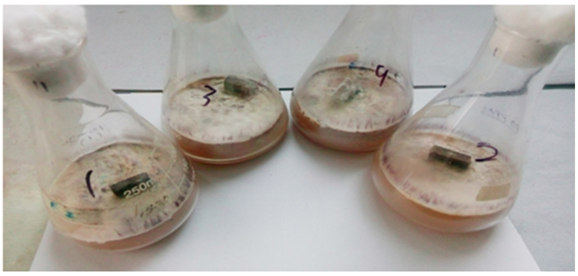


Fig. 8. Fungal (*F. oxysporum*) growth on Ql-raw and Ql-g-poly-(AA-co-MMA) wood after 18 d.

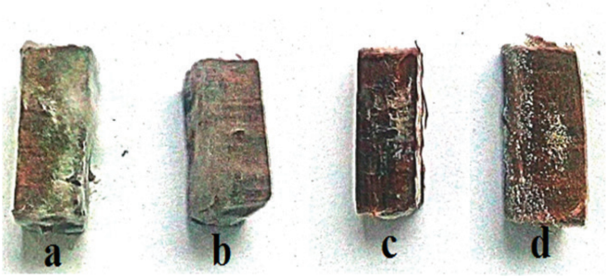


Fig. 9. Fungal growth on (a) and (b) Ql-raw, (c) and (d) Ql-g-poly(AA-co-MMA).

copolymerisation of binary mixture of (AA+MMA) monomer is an effective method. There is considerable influence observed on the physicochemical properties, morphological as well as fungal resistant properties after the graft copolymerisation of MMA+AA binary mixture on the raw wood. Ql-g-poly(AA-co-MMA) shows more resistant to the attack of acid and base, also inhibits the fungal activity and shows less swelling in water. However, the percent crystallinity and crystallinity index of Ql-g-poly(AA-co-MMA) decrease due to disorientation of wood cellulosic crystals as a result of poly(MMA+AA) chains. Thus, to enhance the properties of wood and to increase its utility in different applications, it is necessary to modify the chemical properties of wood.

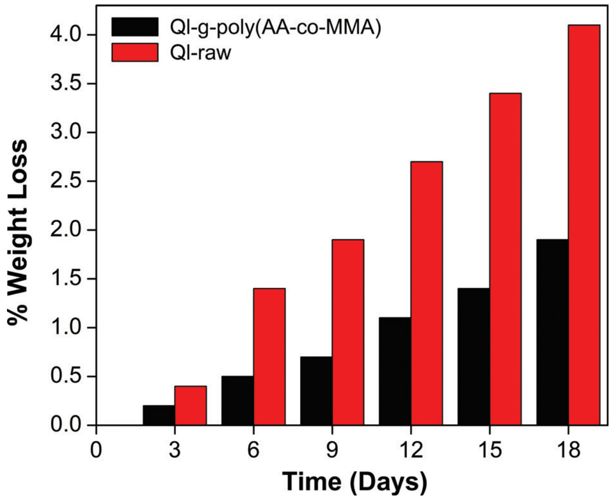


Fig. 10. Percent weight reduction due to *F. oxysporum* in Ql-raw and Ql-g-poly(AA-co-MMA) wood.

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