Bismaleimide blends as novel composites for mechanochemical protection of in-service components

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Bismaleimide blends as novel composites for mechano-chemical protection of in-service components

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ABSTRACT

Bismaleimide (BMI) is a high-performance thermosetting resin widely used in the aerospace, automotive, and mechanical and electronics industries due to its chemical and mechanical stability. It can act as a protective barrier against for steel and other metallic components which serve as magnets, aircraft components. Carbon Nanofibre (CNF) reinforced BMI has shown improved performance as advanced material which has been shown here with surface morphological changes along with the chemical protection imposed by BMI.

Keywords: Bismaleimide (BMI), protection, Carbon Nanofibre (CNF), composite, aircraft

1. INTRODUCTION

Bismaleimide (BMI) resins are a class of high-performance thermosetting polymers with several advantageous properties that make them perfect for usage in a wide range of industrial applications, particularly those requiring aerospace components. They are very resistant to a variety of solvents, acids, and water, and they exhibit outstanding mechanical properties, low shrinkage, chemical resistance, and fire resistance. They are insoluble in ordinary organic solvent and soluble in high boiling polar solvents. BMI coating has also been applied to stop rusting. The addition of inorganic materials, like metal oxides, can change the properties of the polymer as an inorganic-organic composite. There are several uses for organic-inorganic composites in the domains of chemistry, biology, electronics, and optics. **[1-5]**.

BMI has been blended with titania, Ferric chloride as well as Graphene sheet. Metallization and APPJ treatment of Bismaleimide have shown better performance as corrosion protection and EMI shielding **[6]**. BMI monomers are molecules with two maleimide functional groups terminating them; they frequently contain several aromatic moieties to improve their curing properties. **Fig. 1a** shows the typical structure of these compounds) **[8]. ** The crystalline and structural configuration of the composite system has been reported earlier **[8-11]**.

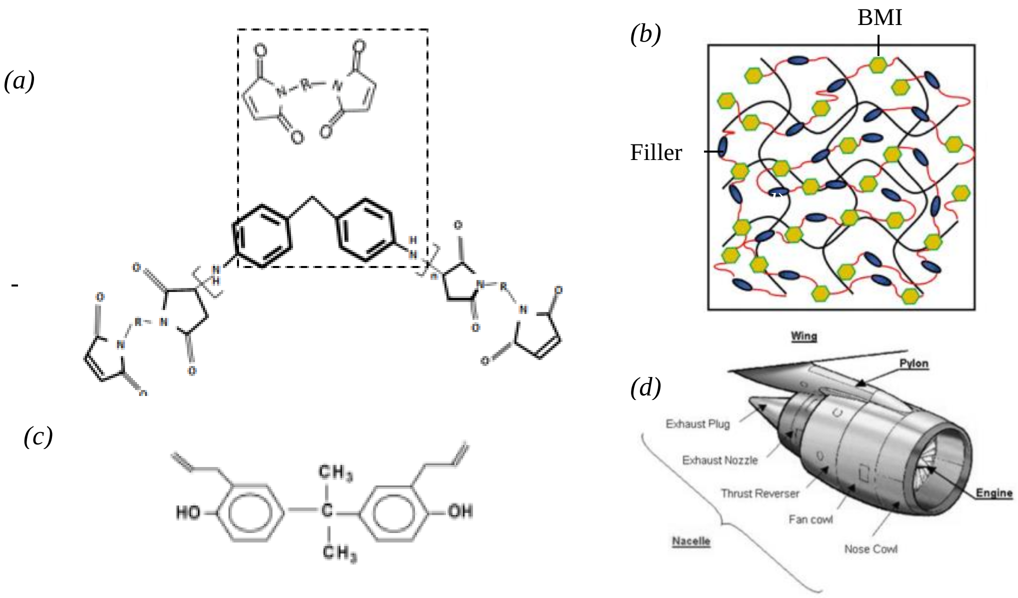

Fig 1: Basic structure of BMI **[9]** (self-drawn) (b)cross-linking of BMI (CC BY 4.0.) **[12]** (c) Diallyl bisphenol A (DABA) **[20]** (d) aircraft nacelle schematic **[22]**

BMI which is also from the family of polyamides having commendable chemical and mechanical properties is a potential ink for polyjets. Inorganic fillers added to BMI enhance the cross-linking causing improved performance (**Fig 1b**) **[12, 13].**

1,1'-(methylenedi-4,1-phenylene) bismaleimide (BMI), which is a thermally polymerizable monomer, is being researched as a safety electrolyte additive for lithium-ion battery thermal protection. The experimental findings show that the BMI additive could polymerize and cause the electrolyte to solidify quickly at 110 °C. This can effectively block off ion transport between electrodes and cause a thermal shutdown of the electrode reactions, allowing lithium-ion batteries to be safely controlled. However, the usual charge-discharge performance of rechargeable lithium batteries remains unaffected by the addition of BMI additive, indicating a promising future for battery applications **[14]**. Thermoplastic modifiers such as polyetherimides, polyether ketone, and polyether sulfone **[15]** increase toughness of BMI. Epoxy such as Thermoset **[16]**, siloxane **[17]**, and Novolac **[18]** can improve the thermo-mechanical properties enhancing its' processibility.

Carbon fibre reinforced BMI from monomers 4-4' bis(maleimido) diphenylmethane copolymerized with 2-2' diallyl bisphenol A(DBA) (**Fig 1c**) have found major application in aircraft structure, especially in the nacelle which the interface between engine and aircraft. It conceals the engine, protects it with a fairing while allowing easy access through cowl openings used for maintenance and repairs, and helps with ventilation and heat management in severely demanding temperature situations. Fibre reinforced BMI are used in its construction as its serves the purpose of being light weight as well as chemically and mechanically robust The fibre-reinforced BMI materials are integrated with the aluminium core into the composite inner cowl design. Some bottle necks the microcracking, and deterioration still needs to be addressed **[19, 20, 21].** Carbon Nano Fibres (CNFs) are curved graphene layers or nano cones stacked to form a quasi-one-dimensional filament **[22]**. They impart high strength to structural components without hampering the overall toughness **[23]**. CNF reinforcements in BMI with different wt% has been reported below along with the chemical protection BMI offers on in-service engineering materials.

2. MATERIALS & METHODS

Homide 250 (Diamino diphenyl methane bismaleimide-diamino diphenyl methane copolymer) was used as the BMI details of which are given in ref **[2, 6, 11]**. The process consisted of BMI being dissolved in distilled water and stirred with PVA and stirred. The solution was applied on mild steel and cured [24]. Aluminium and mild steel sheets with respective thicknesses of 1 mm and 2 mm were used to create the samples. These samples, which served as substrates for the deposition of BMI coatings, were first cleaned and scraped with emery paper to eliminate some ambient rust. They were then polished, hammered to flatten them, and chopped into little pieces, as indicated in Fig. 2a, b [5]. 1%, 3%, 5% (wt %) CNF, BMI were mixed with n,n Di methyl Formamide (DMF) as a solvent and ultrasonicated for 5 hours

Ringers' solution was prepared separately for corrosion test which consisted of boiling distilled water, 0.33 g $CaCl_2$, 0.3 g KCl, and 8.6 g NaCl were combined to create the Ringers solution [5]. The samples were exposed to acetone for approximately 48 hours to eliminate any internal rust. Samples that have been treated with acetone are subsequently given varying amounts of time to react with Ringer's solution. These samples' conditions are examined and contrasted over various time periods. For fifteen days, Al and MS sheets—both bare and coated with BMI—were submerged in the Ringers solution, and every fifteen days, observations were conducted.

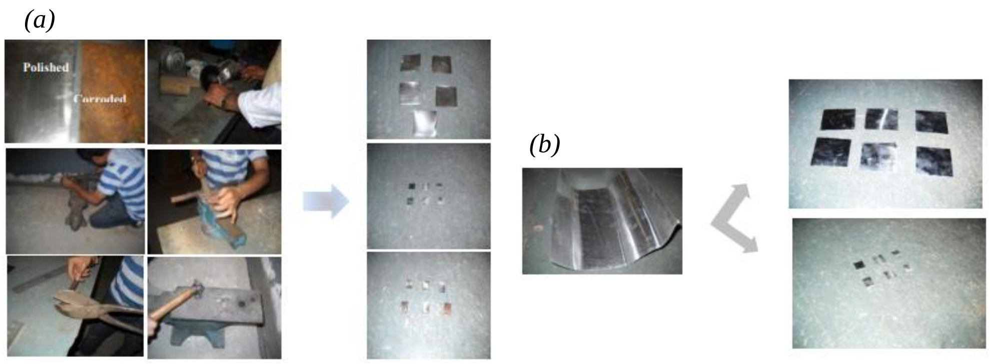

Fig 2(a) Mild steel sheets were polished, hammered, and cut into small pieces (b) Aluminium substrates were cut into small pieces [5]

3. RESULTS & DISCUSSIONS

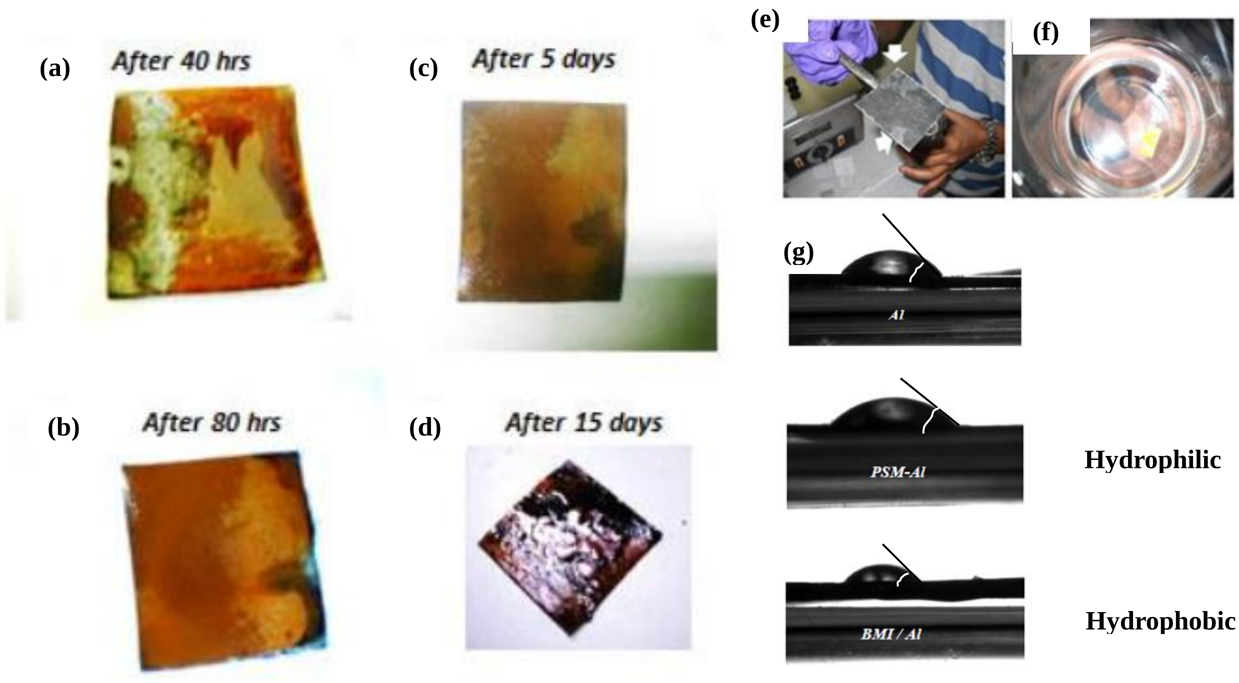

Fig 3. The effect of corrosion on mild steel immersed in Ringer's solution for (a) 40 hrs (b) 80 hrs (c) 5 days and (d) 15 days (e) Corrosion on aluminium substrates and (f) no signs of corrosion on BMI coated substrates (g) Contact angle measurements on the surface of Al, PSM-Al, and BMI/Al [5]

Fig. 3 (a-d) illustrates the effect of corrosion caused by immersing the mild steel substrates in Ringer's solution. It is evident that corrosion has a particularly negative impact in a salty environment. Aluminium resists corrosion better than MS because it forms a protective Al_2O_3 layer on the substrate that stops additional oxidation. However, as Fig. 3(e) illustrates, aluminium can even corrode when exposed to a salty environment over an extended period (Ringer's solution). However, as Fig. 3(f) illustrates, BMI coated aluminium demonstrated resistance to corrosion even after extended exposure to salinized conditions. The protective property of BMI has been also used for Uranium Alloys in water with increased temperature [24], Nd-Fe-B magnets [25]. The high-density PI/BMI co-crosslinking networks post curation have recently shown thermal and flame resistance [26].

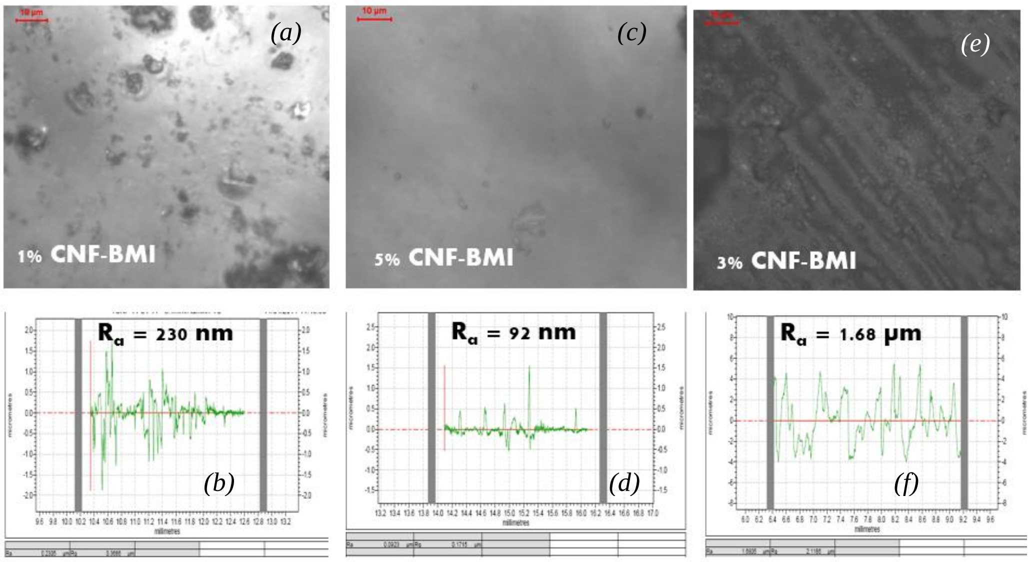

Fig 4. Optical image and roughness profile for (a, b) 1% (c, d) 5% (e, f) 3% Carbon Nano fibre (CNF) reinforced BMI.

Carbon-Nano fibres (CNF) reinforcements is another option which showed very distinct surface morphological transformations from formation from large particulates for 1%, to taking linear shapes for 3% and near amorphous for 5% weight percentage. The average roughness (Ra) (Taylor Hobson surface profilometer) significantly varied, with a highest value of1.68 μm for 3% which aids in adhesion and mechanical protection (**Fig 4**).

The application of atmospheric pressure plasma jet (APPJ) on the BMI surface will also cause surface modification improving the adhesive properties. The contact angle measurements of pristine Al surface, plasma surface modified (PSM) Al surface and BMI coated Al surface are shown in **Fig 3g.** The reduction of contact angle in the PSM-Al surface compared to pristine Al surface indicates increase in hydrophilic nature of the surface which leads to better adhesion of BMI on it. BMI coated Al on the other hand showed hydrophobic nature or water repellent character evident from the increase contact angle reflecting resistance to chemical adversities **[5]**.

4. CONCLUSIONS

Bismaleimide (BMI) showed corrosion protection towards mild steel, aluminium. The cross-linking due to addition of fillers and curing resulted in enhanced density. Carbon nano fibre (CNF) reinforced BMI in increased wt% showed variation in roughness, the highest being 1.68 μm for 3%. BMI/Al were hydrophobic indicating chemical protective propertry. Plasma surface modification (PSM) improved the adhesive property of Al surface where BMI can be configured.

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Conflict of interest
There is no conflict of interest among the authors

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