Preparation and Study of Some Physical and Mechanical Properties of PVA/CMC Blends, for Use as a Treatment for Paper Sheets

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Abstract. This study was conducted in two stages: The first stage: preparing solutions of PVA/CMC binary mixtures, with different weight fractions of CMC (0, 25, 50, 75, 100%) for the purpose of preserving them from damage, and studying some of their physical and mechanical properties, which included (viscosity, drying speed, adhesion strength, traction resistance, maximum tensile stress that the material can withstand before reaching the fracture stage, maximum fracture energy, surface hardness and wear reat), and the second stage: preparing solutions of the same mixtures above and in the same previous proportions, for the purpose of treating and coating three different types of paper: Printing cellulose paper, Carton cellulose paper and Cash cellulose paper.With these prepared mixtures, the effect of the increase in the weight fraction of CMC on some physical and mechanical properties of the treated and coated samples was studied, which are represented by the coating thickness, surface hardness, cutting force, brightness, and water absorption.The results showed an improvement in wear resistance, and that increasing the CMC content in the PVA body after a weight fraction of 25% leads to the PVA material being subjected to the concept of granular sphericity. The studied properties showed an increase in thickness, an improvement in the values of surface hardness, tensile and scratch strength, a decrease in the intensity of brightness and gloss, and the occurrence of slight color changes on the treated paper. The results of treatment with the prepared mixture solutions also showed their superiority in moisture resistance, which is an important indicator in overcoming paper porosity and maintaining the plasticity of the cellulosic material, and in improving the mechanical and physical properties. This is considered an effective means of preserving paper files and documents from damage. Laboratory specifications for this polymer mixture were prepared, and their results were discussed.

Keywords: PVA/CMC blends**,** Physical properties, paper sheets, mechanical properties.

INTRODUCTION

Paper is a cellulose material used in various fields, such as writing, printing, drawing, packaging, etc. Moreover, many papers, documents, records, and paper money are associated with our daily lives.Paper is characterized by its porosity, which affects its absorption rate and its sensitivity to water and moisture. In order to avoid this problem, it is treated with materials that create a barrier against water, moisture, and some of the effects of the environment surrounding the paper. Therefore, polymer coatings are used, which form a thin layer of monomers on the cellulose paper fibers that acts as a protective barrier for the paper. This is due to the low cost of polymer coatings and their easy availability [1-3].As paper cultural artifacts may be exposed to aging and deterioration during long-term preservation, which poses a serious threat to their shelf life, the development of highly compatible polymeric preservation materials is expected to extend the life of paper artifacts due to their excellent compatibility with paper, high optical transparency, outstanding mechanical strength, and large specific surface area[4].Protecting manuscripts and documents means providing them with the appropriate factors, whether they are in storage, on shelves, or in the hands of users, in a way that ensures their safety from any parasitic or environmental infection or human injuries. Then comes the step of maintenance and restoration so that they are intact as their copyists left them, without affecting their physical characteristics [5].

In 2022, Aya and Al-Sarraf studied the physical and mechanical properties of treated paper. They used three types of environmentally friendly transparent polymer coating solutions: nitrocellulose, PMMA, and PVAc. They studied the changes that coating treatments bring about for various paper documents, improving some mechanical and physical properties and protecting them from deterioration and damage. The results showed that coatings with the prepared polymer solutions formed a transparent layer that led to an increase in thickness, hardness, and folding tolerance, while reducing the intensity of gloss and brightness compared to the treated nitrocellulose coating. Meanwhile, the treated polyvinyl alcohol coating led to a significant increase in tensile strength. Furthermore, the treated polymethyl methacrylate coating demonstrated superior moisture resistance. Therefore, it is considered an effective method for preserving paper documents and files from damage [6]. In 2023, R Zhu, et.al aimed to manufacture paper with excellent potential in packaging materials using biopolymers, they used carboxymethyl cellulose (CMC), collagen fibers (CF), and modified polyvinyl alcohol (MPVA). The results showed that the coated paper created layers with high resistance to water and oil and low air permeability [7]. In 2024 Taylor, et.al, study aimed to investigate the effect of CMC on PVA/CMC/CNF nanocomposites, as nanocomposites are characterized by their physical and tensile properties that can affect coating performance. The coating process was carried out on paper and the results showed that increasing the CMC concentration led to an increase in viscosity and improved the tensile properties of PVA/CMC/CNF nanocomposites, good water resistance and tear resistance of the coated paper [8]. The aim of this manuscript is to prepare solutions of PVA, CMC and their PVA/CMC blends and use them as curing coatings for three cellulose paper models. Tribological, physical and mechanical tests of the prepared blends before and after use as curing coatings are also conducted to provide adequate protection to extend their service life and create suitable conditions to protect them from most of the factors that lead to their deterioration or alteration of their properties and characteristics.PVA is a biocompatible, non-toxic, water-soluble material that bonds to cellulosic materials. It is primarily used in fiber and laminate products such as paper wrappers, and in the pharmaceutical and packaging industries, and is safe [9]. CMC is a non-toxic, non-allergenic, highly viscous linear ionic polymer, a water-soluble cellulose derivative [10]. It is used in adhesives as a viscosity modifier or thickener to stabilize emulsions in various products.

PRACTICAL (MATERIALS AND METHODS)

Sample preparation steps

To prepare the PVA and CMC solution samples, 20g of polyvinyl alcohol and carboxymethyl cellulose were taken and each of them was dissolved in 500ml of distilled water, as it is considered a safe and good solvent for the polymers used. To obtain a homogeneous solution, a magnetic stirrer was used in the mixing process for an hour at a temperature of 80°C. After that, both the PVA solution and the CMC solution were cooled at room temperature while continuing to stir for one hour to ensure the homogeneity of each solution. Solutions of binary PVA/CMC mixtures, with different weight fractions of CMC (0, 25, 50, 75, 100%), were prepared at room temperature by mixing the mixture solution using a magnetic mixer to obtain a homogeneous solution. The mixtures prepared with different weight fractions of CMC were placed in Pyrex glass containers and used in two stages. In the first stage, samples were taken from each weight fraction to study their physical properties, and other samples were poured into a mold to study their mechanical properties, which included (viscosity, drying speed, adhesion strength, tensile strength, maximum tensile stress that the material can withstand before reaching the fracture stage, maximum fracture energy, surface hardness, and wear resistance). The second stage: Solutions of the same mixtures above were used, in the same weight fractions, to treat and coat three different types of paper: Printing cellulose paper, Carton cellulose paper and Cash cellulose paper. This was done by immersing them individually for 15 minutes in each weight fraction of the prepared mixtures. Then, the effect of the increase in the weight fraction of CMC on some physical and mechanical properties of the treated and coated samples was studied, which were represented by drying time, coating thickness, surface hardness, cutting force (brightness), water absorption or moisture absorption.

RESULTS AND DISCUSSION

Initial investigations of the specifications of the prepared polymer mixture in terms of some of its physical and mechanical properties showed that the prepared solutions and their mixtures in general dry and solidify at room temperature (27±2) degrees Celsius once the solvent evaporates from them, leaving the polymer mixture. It was found that the polymer mixture generally turns into a solid state in a completely dry form after 4 hours, while touch dryness occurs within a period of 60 minutes.

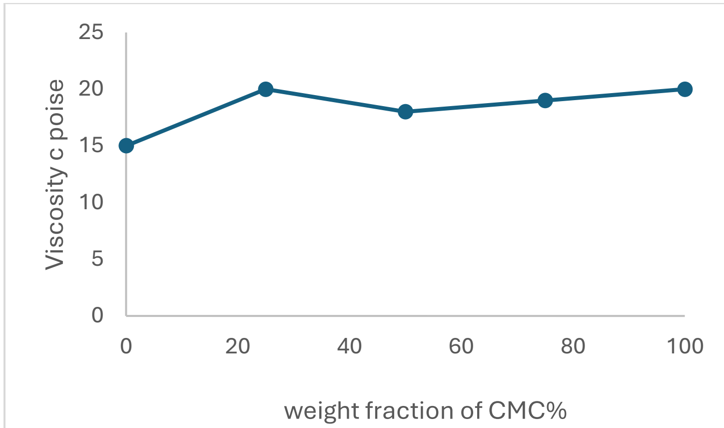

FIGURE 1. The relationship between viscosity and the increase in weight fraction of CMC%.

Figure (1) shows the behavior of the viscosity of the prepared polymeric mixture with the increase in the weight fraction of the CMC solution, where we notice that the viscosity of the polymeric mixture, which represents the resistance of its particles to flow when the weight fraction of the CMC increases, where we notice that there is a turning point or transition point which can be determined at a weight fraction of 25% of the CMC. This means that the more the weight fraction of the CMC increases in the prepared mixture, which is a viscosity-modifying or thickening substance, the stability of the polymeric mixture is achieved. However, this increase continued for a weight fraction ranging around 25%. This weight fraction represents the turning point after which the viscosity of the mixture begins to gradually decrease slightly, because with the increase in the weight fraction of the CMC, the adhesive material turns from a viscous liquid material in which the viscosity measurement is achieved into a brittle, crumbly material subject to the concept of granulation or granular balling, and this is what the researcher [11] explained, as the granular balling process (Agglomeration) depends on the CMC content in the mixture. At high weight fractions, clumps will occur in the polymer mixture due to the difficulty of merging the two solutions during the preparation process.

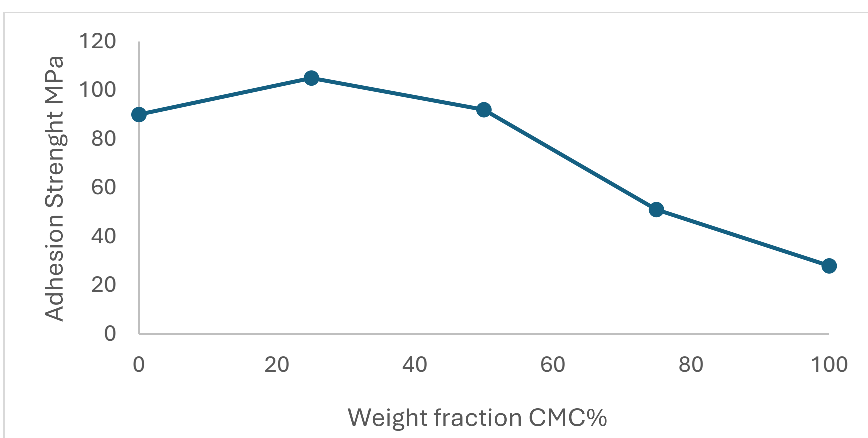

FIGURE 2. The relationship between adhesion strength and weight fraction increase of CMC%.

Figure 2 illustrates the behavior of the adhesion strength with the increase in the weight fraction of CMC, where we notice an improvement in the adhesion strength up to the weight fraction of 25% of the CMC, where the prepared mixture obtained the highest percentage of the adhesion strength value, where the increase in the weight fraction had an effect on raising the viscosity of PVA in the prepared mixture, which in turn led to improving the flow ability and stabilizing it in a way that eliminates high flow ability, but the results showed that increasing the weight fraction of CMC over 25% will negatively affect the properties of the prepared mixture, not only the adhesion strength values but even the Tensile Break results, this is what we notice in Figure (3).

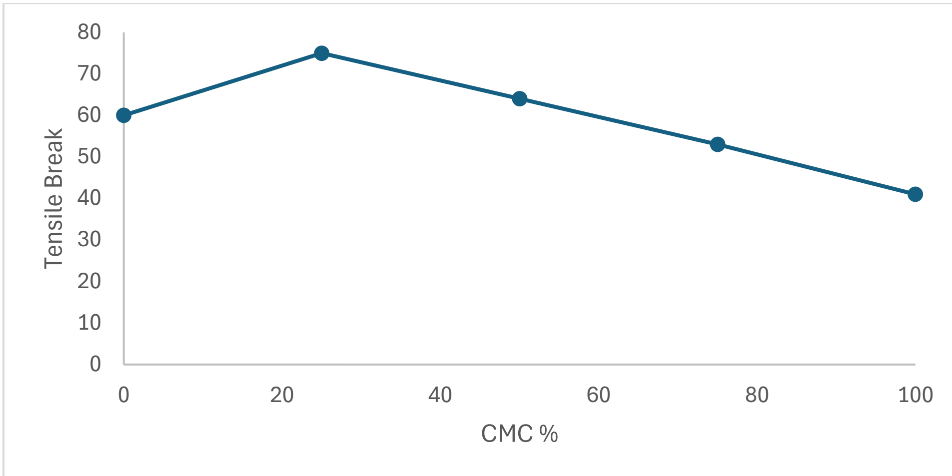

FIGURE 3. The relationship between adhesion strength and weight fraction increase of CMC.

We note that a weight fraction higher than this will affect the values of the maximum stress and modulus of elasticity that the prepared mixture material can bear before failure. This is attributed to the fact that an increase in the weight fraction of CMC above 25% leads to the occurrence of granular sphericity and the transformation of the mixture material into a brittle, crumbly material subject to the concept of granulation[11].

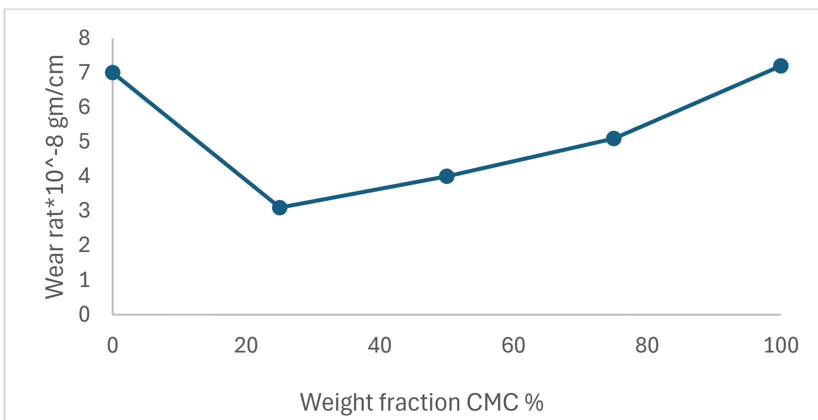

FIGURE 4. The relationship between the wear rate and the increase in the weight fraction of CMC%.

This is evident in Figure (4), which illustrates the behavior of the wear rate of the polymeric blend with the increase in the weight fraction of CMC. It is clear from this that the lowest wear rate was achieved at a weight fraction of 25%, after which the wear rate increased with increasing CMC content in the blend.From Figures 1 to 4, we can see the consistency of the results and the determination of the best value for the specifications of the prepared polymeric blend. To study the effect of increasing the weight fraction of CMC in the prepared polymeric blend on the physical and mechanical properties of the treated paper samples, we note from Figure (5) the effect of increasing the weight fraction of CMC on the thickness of the coating material. From the figure, we can see the behavior of the thickness change of cellulose paper samples treated with polymer coating solutions with increasing weight fraction of polymer in the solution. We generally observe an increase in the thickness of the samples with increasing weight fraction of polymer. We also note that the cardboard samples treated with polymer coatings had a higher thickness, while the samples of treated regular paper had a lower thickness. This may be attributed to the fact that the samples treated with the prepared mixture solutions formed a bridge of monomers during the polymer deposition process in the form of a film, and it also played the same role in the treated cardboard samples [7].From Figure (5), we can see the behavior of the thickness change of cellulose paper samples treated with polymer coating solutions with increasing weight fraction of polymer in the solution. In general, we can see an increase in the thickness of the samples with increasing weight fraction of polymer. We also note that the cardboard samples treated with polymer coatings had a higher thickness, while the samples of treated regular paper had a lower thickness. This may be attributed to the fact that the samples treated with PVA solutions formed a bridge of monomers during the polymer deposition process in the form of a film. It also played the same role in the treated cardboard samples, as in Figure (5) [7, 12].

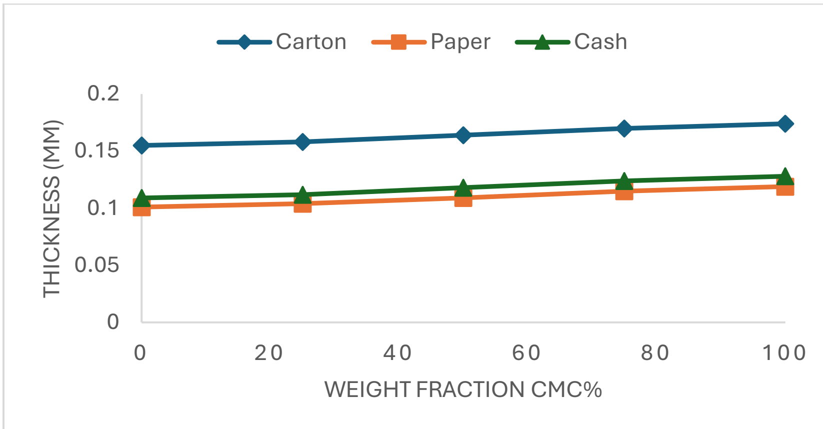

FIGURE 5. The relationship between thickness and the increase in the weight fraction of CMC% for different materials.

Figure (6) shows the behavior of the change in hardness values of samples treated with polymer coating solutions with increasing weight fraction values of PVA polymer in the coating solution. We notice an improvement in hardness values with increasing weight fraction values of PVA polymer in the solution. The cardboard samples had the lowest hardness value, while the paper samples had an average hardness value. The treated banknote samples also had the highest hardness values for all weight fractions. The improvement in hardness values with increasing weight fraction shown in Figure (6) will help the cellulose paper samples treated with polymer coatings resist scratching and deformation. This means that the distance between their polymer chains has become smaller, which increases their resistance to plastic deformation [13].

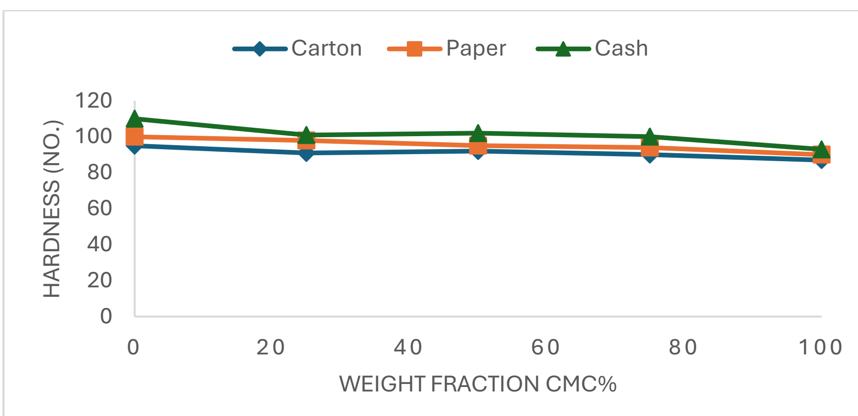

FIGURE 6. The relationship between surface hardness and the increase in the weight fraction of CMC% for different materials.

Figure (7) shows the behavior of the change in tensile strength (cutting force) values of samples treated with polymer coating solutions with increasing weight fraction values of PVA polymer in the coating solution. The tensile strength (cutting force) of the material represents the maximum tensile stress that the sample can withstand before it breaks, Which was calculated by the researcher's device Rola and Mohammed[14]We note that the paper and cardboard samples showed an improvement in the cutting strength values, but the cash samples outperformed by having the highest cutting strength values. This means that the coated paper has a high tolerance to deformation and extension because the polyvinyl alcohol polymer has high flexibility and the carboxymethyl cellulose polymer is characterized by the bonding and elongation between the paper fibers. This means that both polymers showed an improvement in the cutting strength and thus improved the mechanical properties. This is consistent with [15-16].

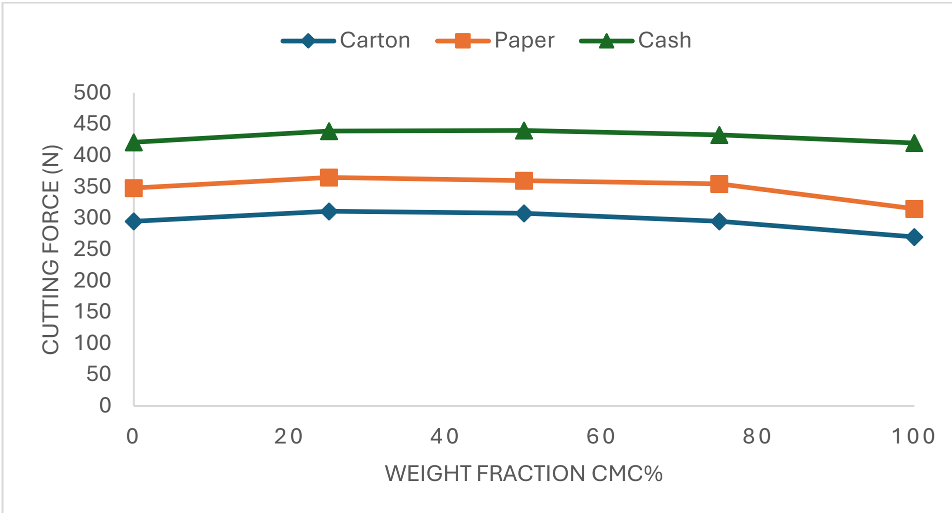

FIGURE 7. The relationship between the cutting force and the weight fraction increase of CMC% for different materials.

Figure (8) shows the behavioral relationship between the degree of brightness and the increase in the weight fraction of the polymer in the treated coating solution, where we notice a slight decrease in the degree of brightness with the increase in the fraction, and the samples of regular paper treated with PVA coating gave a higher degree of brightness than the other coatings, followed by the cardboard samples treated with polymer coating, while the banknote samples gave a lower degree of brightness than the rest of the samples, and for all weight fractions, the color degree had very slight changes, which means that the coating did not change the color of the treated cellulose samples because the polymer coating used has high transparency, and this is consistent with [17].

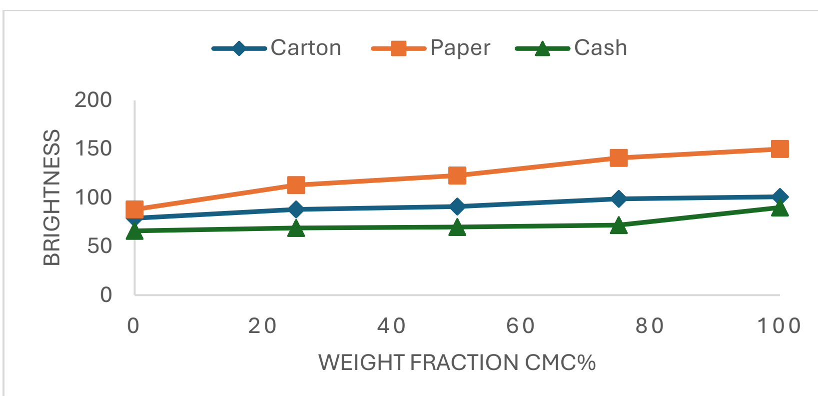

FIGURE 8. The relationship between the degree of brightness and the increase in the weight fraction of CMC% for different materials.

Figure (9) represents the relative behavior of the moisture content of cellulose paper samples treated with polymer coating solutions, which provides significant and significant indicators of their ability to overcome the porosity of cellulose paper, leading to a decrease in moisture content. We observe a decrease in moisture content as the weight fraction of the polymer in the coating solution increases. The treated cardboard samples had the lowest moisture content compared to the treated conventional paper samples. The decrease in the moisture content index of conventional paper is due to its water resistance, which is beneficial for maintaining the plasticity of the cellulose material. The critical samples, however, demonstrated significant improvements in moisture content and resistance to water and wetness. The decrease in moisture content will lead to an improvement in the mechanical and physical properties of cellulose paper, as moisture causes laxity and weakness in the bonds between cellulose fibers, thus affecting the ability to withstand folding endurance, tensile strength, cutting, and tearing, which is consistent with [18].

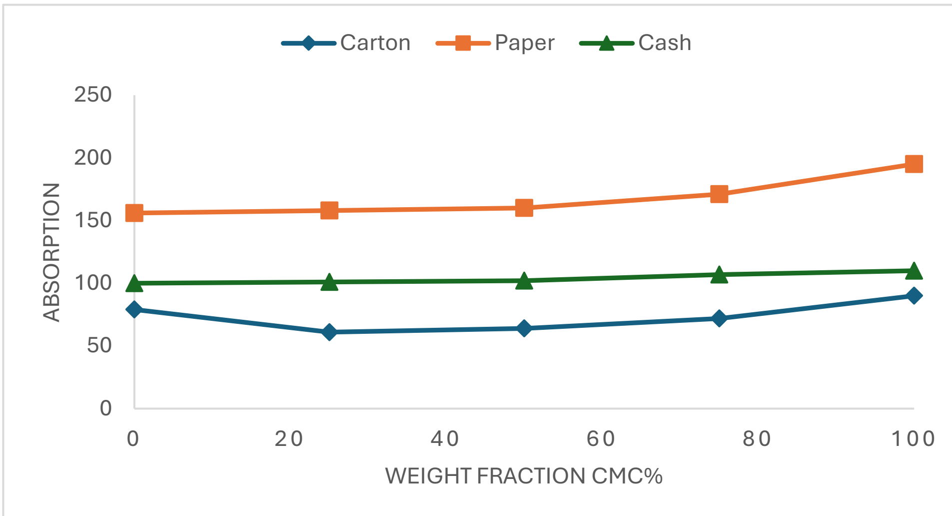

FIGURE 9. The relationship between moisture absorption and the increase in the weight fraction of CMC% for different materials.

CONCLUSION

The results showed that the polymer coatings formed a transparent layer, resulting in increased thickness, hardness, and bending resistance. A decrease in the gloss intensity of the treated coating. The treated coating was superior in moisture resistance compared to the paper samples. The polymer coating solution demonstrated superiority in improving physical properties. It was also distinguished by its safety, as water was added as a diluent when prepared, unlike other polymer adhesive solutions, which require thinner as a diluent, which emit a strong odor that can be hazardous to health if inhaled. It is also inexpensive and readily available.

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