

Evaluation of Old Corrugated Container (OCC) by Blending with Carboxymethyl Cellulose (CMC) and Amphoteric Polyacrylamide (aPAM)

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Abstract

The increasing demand for sustainable and eco-friendly materials has driven significant interest in enhancing the mechanical properties of recycled fibers, particularly old corrugated container (OCC) paper, through the incorporation of additives like carboxymethyl cellulose (CMC) and amphoteric polyacrylamide (aPAM). The aim of this study is to evaluate the change on the old corrugated container (OCC) paper when blending with carboxymethyl cellulose (CMC) and amphoteric polyacrylamide (aPAM) as the dry strength additives (DSA). In the study, the condition involve 100% of OCC with 5 different percentages of DSA which is 0.5%, 1.0%, 1.5%, 2.0% and 2.5%. The experiment in preparing the paper and paper testing is based on the TAPPI and MS ISO standards. Based on the result of the study, dry strength additives improve the paper's mechanical properties. In the ANOVA analysis, a significant result can be observed from the tearing index, the value is getting increasing when addition percentage of DSA that can reach 7.46 m.N.m²/g for the 100% OCC pulp with 2.5% CMC and 13.39 m.N.m²/g for 100% OCC pulp with 2.5% aPAM. Meanwhile, in the busting index and tensile index, they are also increase in different percentage of DSA for the ANOVA analysis. In the busting index, the highest value recorded at 2.83 kPa.m²/g for 100% OCC pulp with 2.5% CMC and the value for 100% OCC pulp with 2.5% aPAM is 2.62 kPa.m²/g. For the tensile index, the highest values recorded at 1.20 N.m/g for 100% OCC pulp with 2.5% CMC. In the morphology analysis, the increased DSA will improve structure for paper such as less pores and broken fiber on the paper surface. When comparing CMC and aPAM, aPAM at 2.5% provided the highest improvement in the tearing index, while CMC at 2.5% showed better results for the bursting and tensile indices. Therefore, the choice between CMC and aPAM depends on the specific mechanical property that needs enhancement, with aPAM being more effective for improving the tearing index and CMC being better for enhancing the bursting and tensile indices. In conclusion, the addition of DSA in the paper properties improves the structure and mechanical properties of the paper.

1. Introduction

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Over the years, the sustainability of pulp and paper operations is a complex issue involving the environment, economy, and society. Many studies have explored various aspects of sustainability in this sector, providing insights into environmental impacts, resource management, regulatory effects, and how communities sustain themselves. Therefore, the utilization of non-wood biomass in the pulp and paper industry has been explored as a feasible and cost-efficient alternative to fibrous wood, highlighting the environmental benefits and potential income from papers produced [1]. Among the recycled materials suitable for paper production is old corrugated container (OCC) paper, often recognized as corrugated cardboard or cardboard paper. One of the main benefits of OCC paper is its environmental sustainability. In Malaysia, the recycling rate for paper, including OCC, has been reported to be around 28.1%, exceeding the targeted rate of 22% [2].

OCC is a potential source of recycled fiber for paper and paperboard manufacture, but it has some disadvantages such as a decrease in the quality and strength of the fiber during the recycling process [3], [4]. To address this issue, combining OCC with Carboxymethyl Cellulose (CMC) and Amphoteric Polyacrylamide (aPAM) should be explored. By combining these materials, the study aims to create a composite material that is stronger, more durable, and environmentally friendly, offering a sustainable alternative to traditional packaging materials. The study from Li *et al* [5] state the addition of an additive has been shown to enhance the properties of recycled OCC paper, resulting in increased tensile, tear, and burst indices.

Carboxymethyl cellulose (CMC) is a versatile and abundant material with various applications in different fields. The introduction of carboxymethyl and hydroxyl groups on the cellulose makes it highly soluble in water and chemically reactive, making it suitable for various applications such as drug delivery, tissue engineering, food industry, cosmetics, paper, and dyeing[4]. From the website fortune biotech [6] the recommended dosage of CMC is between 0.2% and 0.8% of the paper pulp. By using CMC, the paper's tensile strength is enhanced by 40%-50%, its tearing resistance is raised by 50%, and its flexibility is multiplied by 4-5 times.

While Amphoteric polyacrylamide (aPAM) is a versatile linear water-soluble polymer that is utilized in various fields such as papermaking, wastewater treatment, and oilfield profile control [7]. It is a polyampholyte, containing both basic and acid groups along its molecular backbone chain, which contributes to its unique properties [8]. The molecular weight of aPAM can be influenced by synthesis variables, impacting its performance in applications like dry strength improvement in paper sheets [7]. The previous study from Wang *et al* [9] state the versatility of aPAM is further demonstrated by its application solely or in combination with cationic starch for paper strength improvement, showcasing its potential in enhancing paper properties

Blending techniques in papermaking are crucial for determining the properties and quality of the final paper product. The incorporation of different fibers and materials through blending processes significantly impacts the physical and mechanical characteristics of paper. For the utilization of mechanical blending and pulp blending in papermaking has been shown to improve tensile strength and overall physical properties of the resulting paper [10]. These studies collectively demonstrate the significant effects of blending on paper properties, including strength, thermomechanical behavior, and mechanical properties, emphasizing the importance of blending techniques in enhancing the overall quality and performance of paper products.

The aim of this study is to implement the CMC and aPAM in restructuring the bonding between the OCC pulp and the recycled pulp in different doses of condition. In implementing the different of results, different types of conditions and doses are used to determine the different results in the study. To fulfil the requirement of the TAPPI and MS ISO, various doses parameters are used to determine the different type of properties on the paper. After conditioning the papermaking, the paper will be tested on the structure and mechanical properties according to the TAPPI and MS ISO standard. To determine the data analysis, Analysis of Variance (ANOVA) have been used to determine statistical analysis. After the data analysis, a Scanning Electron Microscope (SEM) was used to determine the morphology of the structure of the paper.

2. Materials and Methods

2.1 Material

The materials for this study were divided into two main categories which are OCC and DSA, specifically CMC and aPAM. The other materials that are used are a blender, a mould, and water. The OCC paper was sourced from discarded cardboard pieces, ensuring the material was clean and uncontaminated. Detailed sorting was conducted to remove non-paper substances such as plastics and metals, maintaining the integrity of the paper feedstock. The product specifications for the materials used are as follows: OCC, sourced from discarded cardboard pieces, was ensured to be free from non-paper substances such as plastics and metals. CMC and aPAM were used as dry strength additives, with concentrations of 0.5%, 1.0%, 1.5%, 2.0%, and 2.5% each. A blender was used to process the OCC into pulp, and a mould measuring 19 cm by 25 cm was employed to form handsheets. Water was utilized throughout the pulping and papermaking process. Figure 1 shows the material that was used in this study.

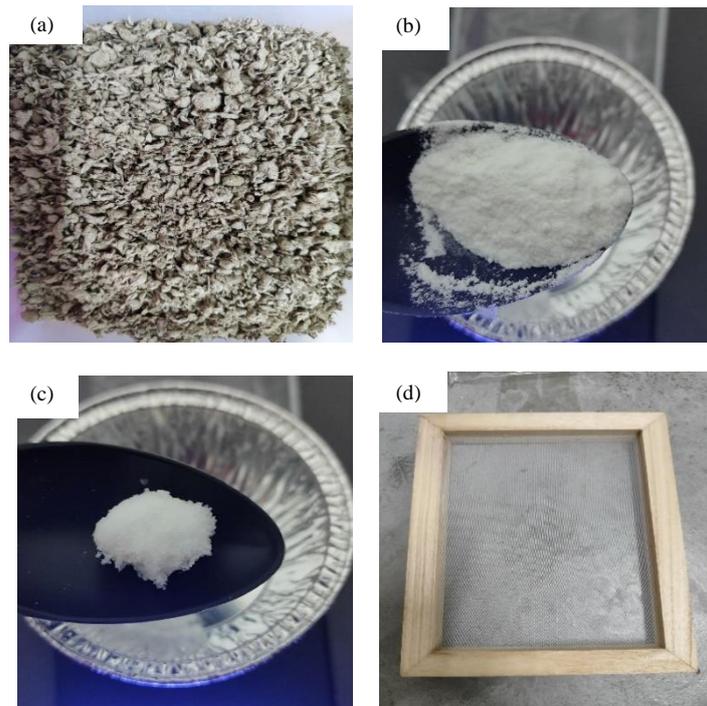


Fig. 1 (a) OCC pulp; (b) CMC; (c) aPAM; (d) mould

2.2 Pulp preparation.

The pulp preparation involved primary stages in processing OCC into pulp. The manual papermaking technique required a systematic approach to ensure high-quality OCC pulp. Initially, discarded cardboard pieces were gathered and sorted meticulously to exclude non-paper substances, thus maintaining the integrity of the paper feedstock. The OCC was then cut into 1-2 cm pieces and processed in a blender to create pulp. The prepared OCC pulp was then blended with varying concentrations of CMC and aPAM (0.5%, 1.0%, 1.5%, 2.0%, and 2.5%) to study their effects on the paper properties. Figure 2 illustrates the blending process of OCC pulp. These prepared pulps were subsequently used for further analysis and handsheet formation to investigate the impact of CMC and aPAM on the properties of OCC paper.



Fig. 2 (a) OCC cut into small pieces, (b) OCC pulp.

In the preparation of the OCC pulp, the doses of the pulp are separated into types of pulp properties that contain 100% OCC pulp blended with 0.5%, 1.0%, 1.5%, 2.0% and 2.5% of CMC & aPAM.

2.3 Handsheet Formation

The TAPPI standard is used as a base for studying handsheet characteristics. To make the handsheet, it's important to follow TAPPI T205 sp-02 (Handsheets Forming for Physical Test), which specifies that the 11 sets in the study should use a 120-gramme handsheet. This standard is made up of the pulp that had remained after making the British handsheet. Initially, 5.7 grams of OCC pulp was weighed to meet the requirement for producing 120 gsm paper. This weighed pulp was then placed into a blender along with the DSA and 1 liter of water per sample. The mixture was blended for 1 minute to ensure thorough disintegration. After blending, the pulp-water mixture was poured into a mould, ensuring even distribution to form a uniform sheet.

For samples requiring CMC or aPAM, additives were introduced at this stage. The specified percentage of CMC or aPAM (0.5%, 1.0%, 1.5%, 2.0%, or 2.5% by weight of the pulp) was added, and the mixture was blended again for an additional minute to ensure even distribution. The mould containing the wet pulp sheet was then carefully transferred to a drying place and dried until completely dry. To ensure consistency and accuracy, these steps were repeated to create one sample per procedure and five samples for each dose.

Once dried, the sheets were tested for physical properties according to the TAPPI-205 sp-02 standards. By following this detailed procedure, OCC paper that met the required standards for forming handsheets for physical testing of pulp was produced, allowing for the evaluation of the impact of CMC and aPAM on the handsheets' physical properties. Figure 3 illustrates the handsheet formation process.

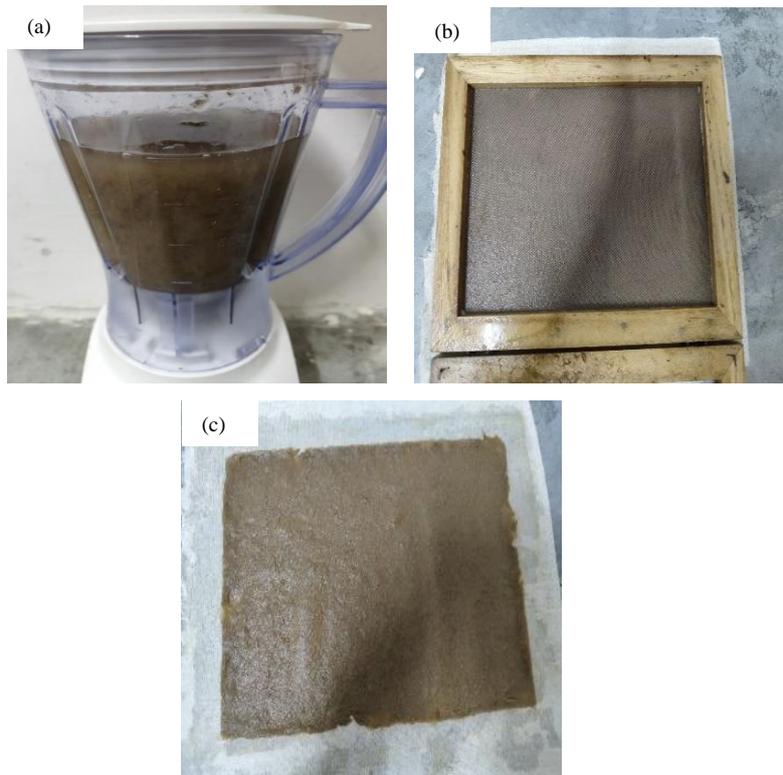


Fig. 3 Handsheet forming process: (a) blending process, (b) the pulp was placed in the mold, (c) drying process

2.4 Determination of Pulp and Paper Properties

To determine the properties of the paper, five types of testing included grammage, thickness, tearing, bulking and tensile. The standard of the testing is according to the MS ISO standard. Table 1 below shows the MS ISO standard that is used to determine the structure and mechanical properties.

Table 1 Structure and Mechanical Properties standard

Testing	TAPPI/ MS ISO
Thickness	MS ISO 534:2005: Paper and board - Determination of thickness, density and specific volume
Grammage	MS ISO 536: 2012: Paper and board - Determination of Grammage

Tearing	MS ISO 1974: 1999: Paper – Determination of Tearing Resistances – Elmendorf Method – Second Revision (ISO 1974: 1990, IDT)
Busting	MS ISO 1974: 1999: Paper – Determination of Bursting Strength (ISO 2758: 2001, IDT)
Tensile	MS ISO 1924-2:2008 Paper and board -Determination of tensile properties

3 Results and Discussion

3.1 Structure Properties

Based on the test results, two types of properties were examined in this study: structural properties and mechanical properties. For the physical properties, the tests focused on determining the bulking density and the apparent density. Meanwhile, the mechanical properties were assessed through tests for tearing, bursting, and tensile strength.

Table 2 below shows the structure properties testing analysis which is thickness and apparent density and ANOVA analysis using Turkey's Range Grouping. To interpret the parameter of the pulp properties, two benchmarks were used for assessing the pulp doses. The benchmarks include OCC is used to determine the pulp that be used in the study. Based on the finding, most of the results are significant when comparing the paper properties with CMC and aPAM. The increasing of doses OCC pulp and addition of DSA in the paper properties willing to increases the tearing resistance of the paper.

Table 2 Result of Structure properties with Turkey's Range Grouping

Handsheet Properties	100% OCC	100%OCC, 0.5%DSA	100% OCC, 1.0% DSA	100% OCC, 1.5%DSA	100% OCC, 2.0%DSA	100% OCC, 2.5% DSA
<u>Structure Properties</u>						
<u>Thickness (μm)</u>						
CMC	413.10 ^C (± 39.60)	424.40 ^C (± 72.40)	554.20 ^{ABC} (± 69.40)	466.30 ^{BC} (± 50.60)	593.70 ^{AB} (± 147.30)	675.40 ^A (± 91.80)
aPAM	413.10 ^A (± 39.60)	373.80 ^A (± 53.20)	415.00 ^A (± 38.60)	419.40 ^A (± 21.35)	417.90 ^A (± 65.50)	420.30 ^A (± 42.80)
<u>Apparent density (cm^3/g)</u>						
CMC	0.29 ^A (± 0.03)	0.28 ^{AB} (± 0.05)	0.21 ^{ABC} (± 0.03)	0.26 ^{AB} (± 0.03)	0.21 ^{BC} (± 0.06)	0.18 ^C (± 0.03)
aPAM	0.29 ^A (± 0.03)	0.32 ^A (± 0.06)	0.28 ^A (± 0.03)	0.28 ^A (± 0.01)	0.29 ^A (± 0.05)	0.28 ^A (± 0.03)

The thickness results for handsheets made from 100% OCC with varying percentages of CMC and aPAM show distinct trends. CMC addition significantly increases thickness, particularly at higher DSA levels, with the highest recorded thickness being 675.40 μm at 2.5% DSA. In contrast, aPAM results in minor changes in thickness, maintaining a consistent sheet structure with thickness values between 373.80 μm and 420.30 μm across different DSA levels. This finding aligns with the study by Kobayashi *et al.*, [11], where increased CMC concentrations led to a notable thickness increase in composites.

Apparent density results reveal notable differences between handsheets with CMC and aPAM additives. For CMC, the baseline density is 0.29 g/cm^3 . Density decreases significantly with increasing DSA concentrations, reaching a low of 0.18 g/cm^3 at 2.5% DSA, indicating a 38% reduction from the baseline. Conversely, handsheets with aPAM exhibit relatively stable densities, with minor variations around the baseline density of 0.29 g/cm^3 . This suggests CMC creates a less dense material with more air spaces, while aPAM maintains a more compact fiber arrangement. The study from J. Kobayashi *et al* [11], observed that CMC-treated handsheets showed enhanced mechanical properties, with density variations depending on CMC concentration and immersion cycles. Then the strategic addition of OCC pulp can enhance certain paper properties and support sustainable production practices, making it a valuable component in the paper industry [12].

3.2 Mechanical Properties

Regarding the mechanical properties, ANOVA analysis indicates that changes in paper properties yield both significant and non-significant results. This is evident from the ANOVA outcomes for tearing, bursting, and tensile tests of the OCC paper. The overall analysis of the handsheet properties shows that increasing the amount of DSA

usually improves the paper's strength. However, at 1.5% DSA, the strength doesn't increase as expected. This could be because the additive might clump together, causing it to spread unevenly and not bond well with the paper fibers, which reduces its effectiveness.

Table 3 Result of Mechanical properties with Turkey's Range Grouping

Handsheet Properties	100% OCC	100%OCC, 0.5%DSA	100% OCC, 1.0% DSA	100% OCC, 1.5%DSA	100% OCC, 2.0%DSA	100% OCC, 2.5% DSA
<u>Tearing index</u> (<i>m. N.m²/g</i>)						
CMC	6.29 ^A (±1.51)	4.68 ^A (±0.83)	6.73 ^A (±1.31)	6.43 ^A (±1.40)	7.17 ^A (±2.69)	7.46 ^A (±1.20)
aPAM	6.29 ^B (±1.51)	8.91 ^B (±1.88)	7.75 ^B (±1.76)	9.05 ^B (±1.42)	10.36 ^{AB} (±1.88)	13.39 ^A (±3.83)
<u>Busting index</u> (<i>kPa. m²/g</i>)						
CMC	2.54 ^A (±0.22)	2.63 ^A (±0.12)	2.58 ^A (±0.13)	2.52 ^A (±0.25)	2.62 ^A (±0.10)	2.83 ^A (±0.40)
aPAM	2.54 ^{AB} (±0.22)	2.06 ^B (±0.30)	2.44 ^{AB} (±0.20)	2.33 ^{AB} (±0.44)	2.56 ^{AB} (±0.27)	2.62 ^A (±0.12)
<u>Tensile index</u> (<i>N.m/g</i>)						
CMC	0.95 ^{BC} (±0.56)	1.13 ^{ABC} (±0.39)	0.76 ^C (±0.39)	1.22 ^{ABC} (±0.42)	1.84 ^{AB} (±0.70)	2.00 ^A (±0.40)
aPAM	0.95 ^B (±0.56)	2.14 ^{AB} (±0.80)	1.48 ^B (±1.06)	2.34 ^{AB} (±0.75)	3.39 ^A (±0.79)	3.61 ^A (±0.93)

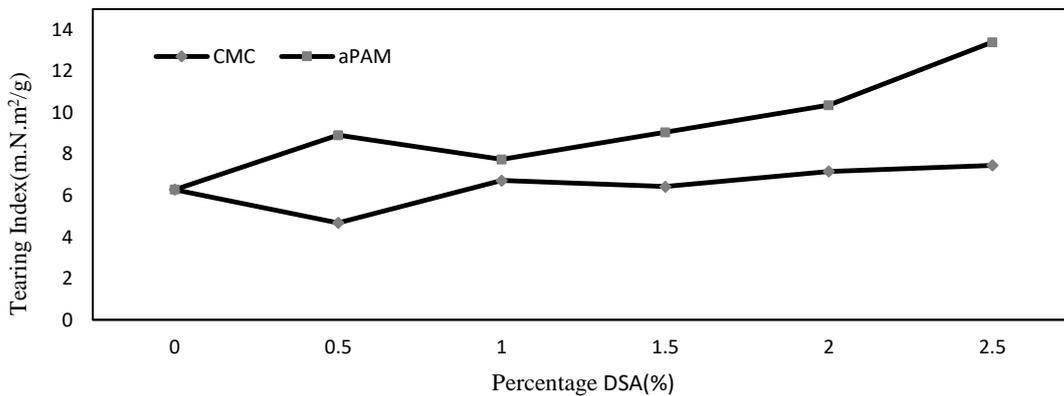


Fig.4 Average tearing index Vs percentage DSA

According to Table 3 and Figure 4 shows the study demonstrates that the tearing index of handsheets varies significantly with different percentages of DSA when using CMC and aPAM additives. While handsheets with CMC initially show a decrease in tearing resistance at lower DSA concentrations 25.52% decrease at 0.5% DSA, they eventually exhibit increased strength at higher concentrations 18.59% increase at 2.5% DSA. Conversely, handsheets with aPAM display a consistent and substantial improvement in tearing resistance with increasing DSA levels, such as an 8.91_m.N.m/g increase at 0.5% DSA and 13.39 m.N.m/g increase at 2.5% DSA. This indicates that aPAM is more effective than CMC in enhancing the tear resistance of paper, particularly at higher DSA concentrations. Therefore, aPAM is a superior additive for applications requiring high durability and strength in paper products. The tearing index, along with other mechanical properties such as breaking stress and breaking

strain, showed substantial improvement. Specifically, paper sheets immersed in a 3 wt.% CMC aqueous solution exhibited a tearing index that was markedly higher compared to untreated paper [11].

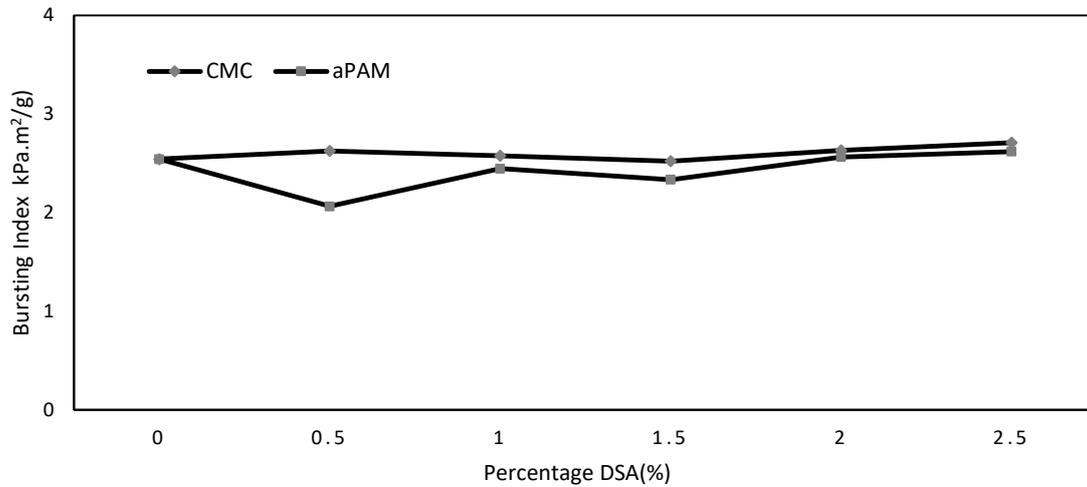


Fig. 5 Average bursting index Vs percentage DSA

Figure 5 and table 3 illustrate the bursting index, which measures the paper's resistance to rupture under pressure, varies with different percentages of DSA and additives CMC and aPAM. For handsheets with CMC, the bursting index initially increases by approximately 3.23% at 0.5% DSA, followed by a slight decrease of 1.34% at 1.0% DSA and a negligible decrease of 0.86% at 1.5% DSA. The index then rises again, showing an increase of 2.99% at 2.0% DSA and a more substantial increase of 11.24% at 2.5% DSA. Compared to the study by J. Kobayashi *et al* [11] concludes that CMC is highly effective in enhancing the mechanical strength of paper sheets, including the bursting index, making it a valuable additive for applications requiring increased durability and resistance to bursting.

In contrast, handsheets with aPAM exhibit a significant initial decrease in bursting index by approximately 2.06 kPa.m²/g at 0.5% DSA, followed by smaller decreases of 3.86% at 1.0% DSA and 8.27% at 1.5% DSA. However, the bursting index starts to recover at higher DSA concentrations, with a slight increase of 2.56 kPa.m²/g at 2.0% DSA and a 2.99% increase at 2.5% DSA. These trends indicate that while CMC-treated papers show minor fluctuations in bursting strength with varying DSA concentrations, aPAM-treated papers experience an initial weakening followed by gradual improvement at higher DSA levels, highlighting the differing impacts of these additives on paper strength. Compared to study upon adding aPAM, the burst strength increased significantly. The trend observed was a steady increase in burst strength with increasing concentrations of aPAM [13].

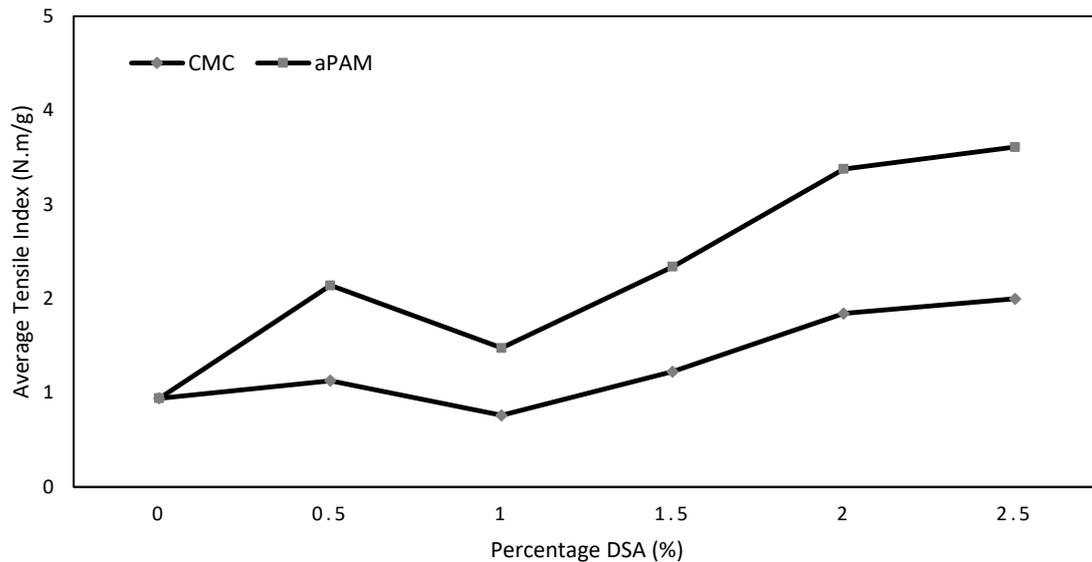


Fig. 6 Average tensile index Vs percentage DSA

Figure 6 and Table 3 show the tensile index, which measures the strength of paper, and indicates **how much the** force is needed to pull the paper apart. This study evaluates the tensile index of hand sheets made from 100% OCC with varying concentrations of DSA and different additives which is CMC and aPAM.

For 100% OCC, the baseline tensile index is 0.95 N·m/g. When 0.5% CMC is added, the tensile index increases slightly to 1.14 N·m/g, indicating a modest improvement in strength. At 1.0% CMC, the tensile index drops to 0.80 N·m/g, suggesting that this concentration may not be optimal for strength enhancement with CMC. With 1.5% CMC, the tensile index rises to 1.22 N·m/g, showing a recovery in strength. This positive trend continues with 2.0% DSA, where the tensile index significantly increases to 1.84 N·m/g. At 2.5% CMC, the tensile index peaks at 2.00 N·m/g, indicating that the highest tested concentration of DSA with CMC results in the strongest hand sheets. The mechanical properties of hand sheets, such as tensile strength, tearing index, and bursting index, generally improve with the optimal use of DSA, but excessive amounts can lead to decreased uniformity and performance [7].

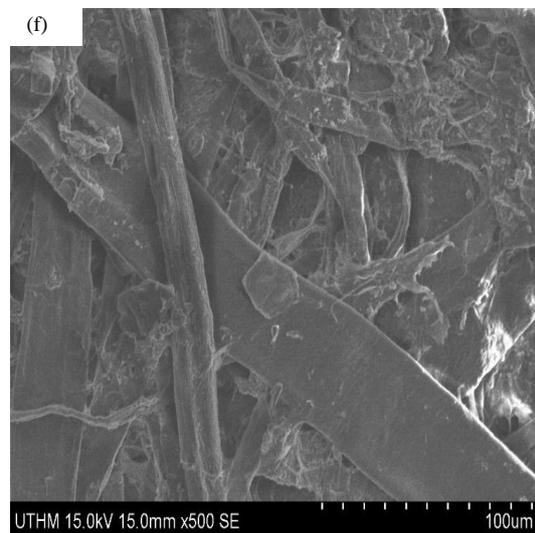
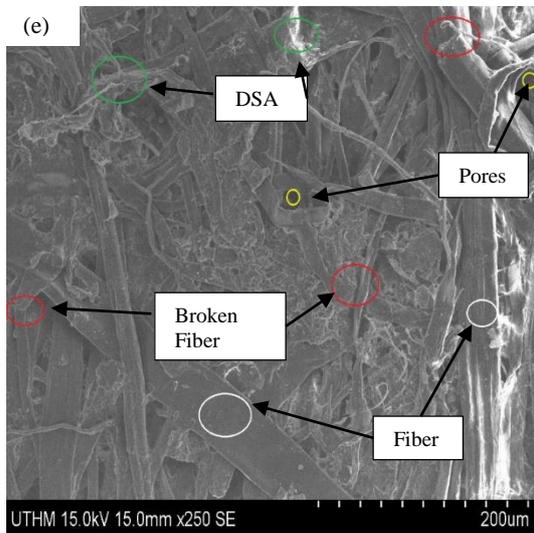
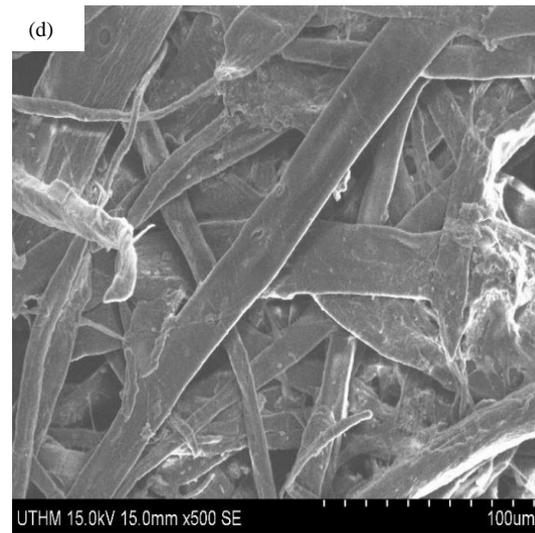
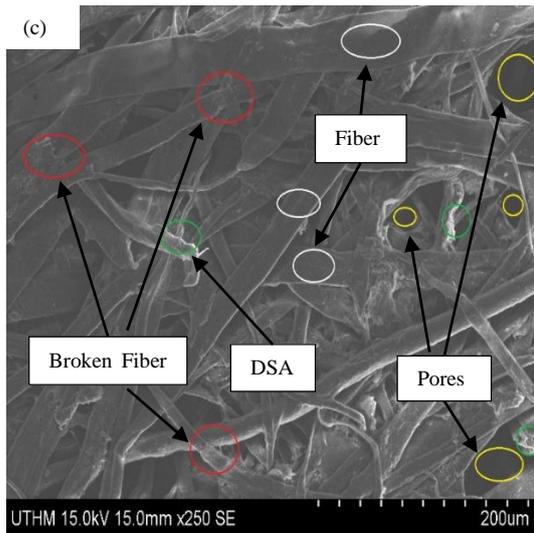
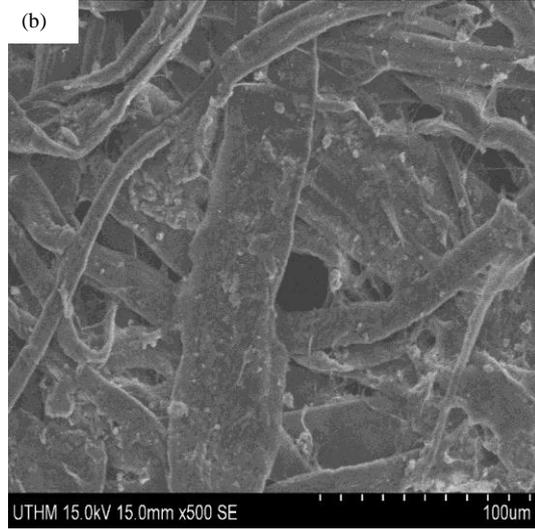
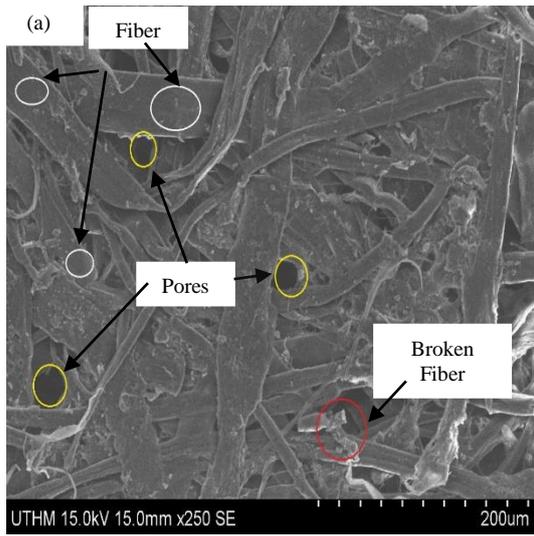
While, adding 0.5% aPAM results in a substantial increase in tensile index to 2.14 N·m/g, demonstrating a significant improvement in strength. At 1.0% aPAM, the tensile index slightly decreases to 1.50 N·m/g but remains higher than the baseline. The tensile index rises to 2.34 N·m/g with 1.5% aPAM showing enhanced strength. At 2.0% aPAM, the tensile index substantially increases to 3.39 N·m/g, highlighting the effectiveness of higher DSA concentrations with aPAM. The highest tensile index of 3.61 N·m/g is observed at 2.5% aPAM, indicating that this concentration produces the strongest hand sheets with aPAM. From the study Zhao *et al* [14] state the trend of using DSA alters the mechanical properties of paper by improving tensile strength and strain at break while variably affecting density, depending on the specific additives used. These changes are driven by the interaction of the additives with the fiber surfaces and their ability to form strong joints between fibers.

From study Nor Mazlana [13], state the results demonstrate that the tensile strength increased notably with the incorporation of aPAM. Specifically, the tensile index showed an approximate 8% increase with the addition of 0.5% aPAM, and this trend continued with higher concentrations.

The results highlight the critical role of both the type of additive and the concentration of DSA in determining the tensile strength of OCC hand sheets. aPAM proves to be superior to CMC, particularly at higher DSA concentrations, making it the preferred choice for enhancing the mechanical properties of OCC-based paper products.

3.3 The Morphology of Handsheet

To identify the morphology structure of the paper, a Scanning electron microscope (SEM) and Energy Dispersive X-ray Spectroscopy (EDX) be used to identify the properties of the paper. 100% OCC paper with 1.5% and 2.5% of CMC then 1.5% and 2.5 % of aPAM be selected to identify the morphology of the paper structure. The morphology image in all figures shows the control magnification from 250X and 500X.



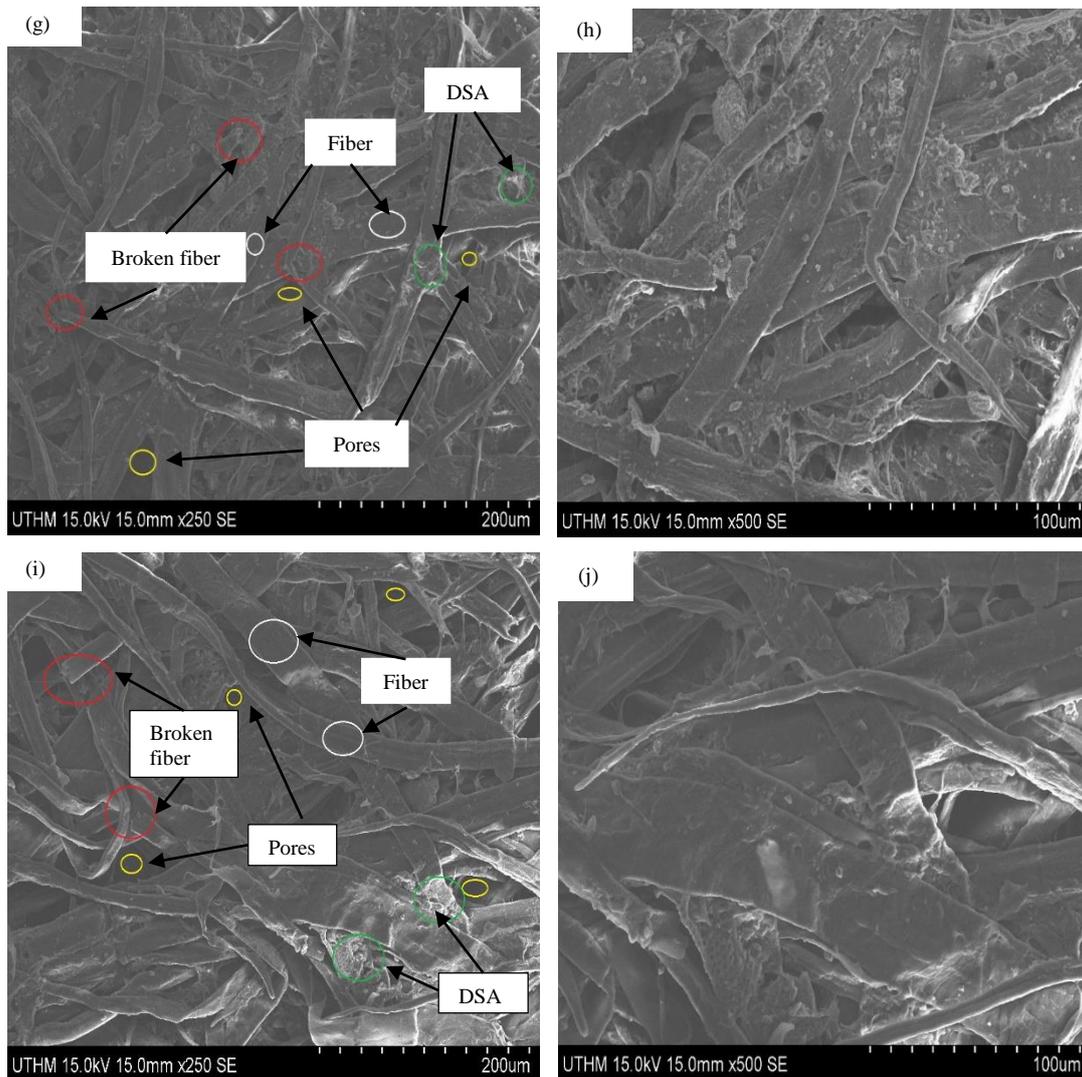


Fig. 7 SEM micrographs of 100% OCC for surfaces viewed at (a) 250 X; (b) 500X; 100% OCC with 1.5% CMC at (c) 250X; (d) 500X; 100% OCC with 2.5% CMC at (e) 250X; (f) 500X; 100% OCC with 1.5% aPAM at (g) 250X; (h) 500X; 100% OCC with 2.5% aPAM at (i) 250X; (j) 500X

Figure 7 illustrates the study of handsheets morphology, particularly through SEM micrographs, reveals crucial insights into the structural and mechanical properties of paper composed of 100% OCC. The micrographs of 100% OCC at magnifications of 250X and 500X show a network of fibers interspersed with pores and broken fibers, indicating inherent weaknesses. Introducing 1.5% CMC into the OCC matrix results in a more cohesive fiber structure, as evidenced by fewer broken fibers and pores. This suggests that CMC enhances fiber bonding, contributing to improved mechanical properties such as higher bursting and tensile indices. At a 2.5% concentration, CMC further consolidates the fiber network, making it denser and stronger.

Similarly, the addition of 1.5% aPAM to the OCC also enhances fiber bonding, reducing the number of defects. The SEM images reveal that aPAM, like CMC, improves the handsheet's morphology by reinforcing the fiber structure. Increasing the aPAM concentration to 2.5% results in even more pronounced improvements, with a tightly bound fiber network and fewer visible defects, indicating enhanced mechanical properties. [\(supported references\)](#)

Comparing the effects of CMC and aPAM, both additives significantly improve the morphology of 100% OCC handsheets, though they do so in slightly different ways. CMC tends to provide a more uniform reinforcement across the fiber network, while aPAM offers targeted improvements in specific areas due to its amphoteric nature. Ultimately, the choice between CMC and aPAM, and their respective concentrations, depends on the desired balance of mechanical properties such as tensile strength, tearing resistance, and burst index. The SEM micrographs clearly demonstrate that these additives play a vital role in enhancing the structural integrity and durability of OCC-based handsheets. The enhanced bonding and reduced voids contribute to the overall strength and durability of the paper [13].

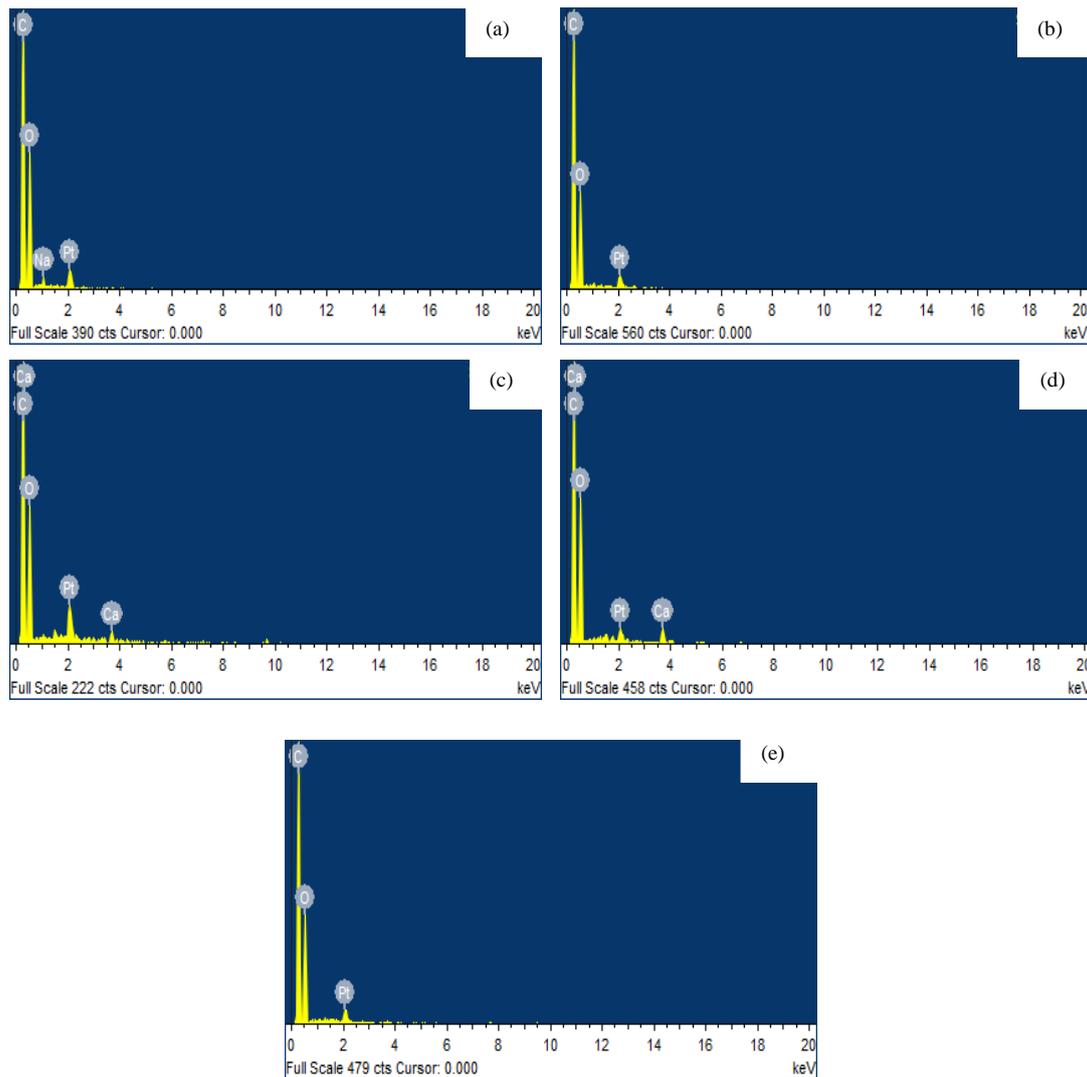


Fig. 8 EDX of 100%OCC with (a) 1.5% CMC; (b) 2.5% CMC (c)1.5% aPAM; (d) 2.5% aPAM; (e) 0% DSA

Figure 8 provided EDX analysis of 100% OCC treated with various concentrations of CMC and aPAM reveals significant insights into their elemental composition. The EDX spectrum for 1.5% CMC treatment indicates the presence of key elements such as carbon and oxygen, along with possible residual elements from the OCC fibers. The addition of 1.5% CMC enhances the binding properties of the paper due to its adhesive nature. Increasing the CMC concentration to 2.5% likely results in a higher carbon content, reflecting improved fiber bonding, which enhances the paper's strength and flexibility.

Similarly, the EDX spectrum for 1.5% aPAM treatment shows elements akin to those in the CMC treatments but with different intensity levels. The aPAM, being a copolymer, contributes to better dispersion and interaction with OCC fibers, thus improving the paper's structural integrity. The spectrum for 2.5% aPAM treatment likely shows an increased carbon presence, indicating better inter-fiber bonding and enhanced durability of the paper.

In contrast, the EDX spectrum for untreated 100%OCC serves as a control, highlighting the baseline elemental composition of the OCC fibers without any additive influence. Comparing the spectra of CMC and aPAM treatments, it is evident that both additives increase the carbon content, indicating their significant role in enhancing the paper's physical properties. Higher concentrations at 2.5% of both CMC and aPAM show a more pronounced impact on the elemental composition, suggesting better performance in terms of dry strength and durability. The untreated OCC provides a reference point, emphasizing the enhancements achieved using these additives. Overall, the EDX analysis effectively demonstrates the impact of different concentrations of CMC and aPAM on the elemental composition of 100% OCC, underscoring their importance in improving paper properties.

4 Conclusion

In conclusion, the study on evaluating the properties of OCC paper blended with CMC and aPAM has demonstrated significant improvements in the mechanical and structural properties of the paper. The addition of these DSA in varying concentrations of 0.5%, 1.0%, 1.5%, 2.0%, and 2.5% has shown a marked enhancement in the tearing, bursting, and tensile indices of the blended paper.

The experimental results, conducted according to TAPPI and MS ISO standards, indicate that higher concentrations of CMC and aPAM significantly improve the mechanical properties of OCC paper. Specifically, the tearing index reached up to 13.39 m.N.m²/g for OCC pulp with 2.5% aPAM, while the bursting index and tensile index also showed considerable improvements with the highest values recorded at 2.83 kPa.m²/g and 2.00 N.m/g for 2.5% CMC, respectively. SEM and EDX revealed that the addition of DSA leads to a more compact and cohesive fiber structure with fewer pores and broken fibers. This structural enhancement contributes to the overall improved mechanical properties of the paper.

Among the two DSA, CMC demonstrated superior performance in enhancing the bursting and tensile indices, making the paper more robust under tensile stress and bursting pressure. On the other hand, aPAM excelled in improving the tearing index due to its effectiveness in forming a cohesive fiber structure that resists tearing forces. This structural enhancement is evident in the SEM micrographs, where CMC-treated papers displayed a denser fiber network, while aPAM-treated papers showed improved fiber cohesion.

Overall, the study concludes that blending OCC with CMC and aPAM not only enhances the mechanical strength and structural integrity of the paper but also offers a sustainable and environmentally friendly approach to recycling OCC. This research provides a viable solution for producing high-strength recycled paper products, aligning with global sustainability objectives and addressing the environmental challenges associated with traditional papermaking practices.

By integrating innovative recycling methods and sustainable material alternatives, this study paves the way for advancements in the paper and packaging industry, emphasizing the potential of DSA in improving the quality and performance of recycled paper products.

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