Passivation of pressure sensitive adhesive stickies by addition of acrylic fibers to OCC pulp before papermaking

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ABSTRACT: This study investigated the addition of acrylic fiber to old corrugated container (OCC) pulp as a possible means of overcoming adverse effects of water-based pressure sensitive adhesives during manufacture of paper or paperboard. Such adhesives can constitute a main source of stickies, which hurt the efficiency of the papermaking process and make tacky spots in the product. The highest amount of acrylic fiber added to recycled pulps generally resulted in a 77% reduction in accepted pulp microstickies. The addition of acrylic fibers also increased pulp freeness, tear index, burst strength, and breaking length, though there was a reduction in screen yield. Hence, in addition to controlling the adverse effects of stickies, the addition of acrylic fibers resulted in the improvement of the mechanical properties of paper compared with a control sample.

Application: These research results reveal possible ways to employ plastic fibers in recovered fiber furnish as a means of overcoming problems with stickies. Not only can the stickies be passivated, but paper properties can be improved as well.

Stickies and tacky substances are common in recovered paper. They can be a source of numerous problems, such as flaws in the appearance of paper sheets and lowering of the efficiency of paper machine operations caused by an increase in the frequency of wash ups, web breaks, and felt plugging [1]. Some of the most difficult problems result from the presence of adhesives such as labels and adhesive tape. Pressure-sensitive adhesives (PSA), which are often a key component of stickies, are organic copolymers and mixtures that may include styrene-butadiene and styrene acrylic latex binders, rubber, vinyl acetates, polyisoprene, polybutadiene, and hotmelts [3]. PSA materials are hard to remove in recycling, and they deposit on equipment and are retained in the product, hampering operations [2]. Adequate management and control of stickies is necessary for the economic health of the industry. There continues to be considerable environmental pressure to increase the use of recycled paper, but its use is not without complications [3].

Deposition of stickies on paper machine surfaces, wires, felts, fabrics, and rolls results in problems such as wet end breaks, press and dryer sections breaks, holes, sheet defects, high dirt counts, and difficulties in paper converting. These deposits and their associated problems cause a significant amount of downtime and waste. The economic impact of stickies rises considerably when the cost of downtime, chemicals costs, production losses, scrap, rejected materials, and customer complaints are taken into consideration [4].

Many studies have focused on the control of stickies. It is clear, however, that no single solution can be found for the many problems caused by stickies on paper and board machines that use fiber [5]. General reviews of control techniques for stickies can be found in several published articles [1,2,5-9].

Physiochemical methods are used to remove or control stickies by the modification of the surface properties of stickies either through adsorption of mineral particles or addition of other chemicals or in combination in order to facilitate the removal or pacification of the stickies. These methods include: flotation, washing, addition of solid materials, and treatment with surfactants and polymers [10]. Dispersants, surfactants, and solvents are used to minimize stickies at various stages of the recycling process. Other approaches use chemicals to agglomerate the stickies in order to enhance their removal at the screening stage. Other chemical treatments aim to make the stickies more hydrophilic to ease their removal at the washing stage. In fixation treatments, the stickies are attached to the paper sheet using a water-soluble polymer, which changes the surface charge of the stickies. In dispersing and fixation treatments, a dispersant is first added to decrease the size of the stickies, and then a cationic polymer is applied in order to adhere the stickies onto the sheet. In passivation, the use of talc, dispersants, solvents, and low molecular weight cationic polymers makes the paper machine less susceptible to stickies [10]. Other researchers have focused on the design of new PSAs with better recyclability properties [11].

The development and the use of a variety of man-made fibers have in recent decades created a revolution in the textile industry [2,6]. It is possible that similar application of synthetic fibers may eventually become widespread in the paper industry. Many specialty paper products are currently made of synthetic fibers [12]. Another study revealed that an addition of 4% to 10% of short-cut polyester staple fibers to bagasse and wheat straw pulp can significantly improve the mechanical properties of the manufactured paper [13]. In certain applications, synthetic polypropylene fibers have been used for scavenging inks and sticky particles from secondary fiber stock. For example, Scav EX 235 is a product of this type that has been supplied by Hercules, Inc. (now Solenis; Wilmington, DE, USA). These types of synthetic fibers have met with some limited success [14].

Acrylic fibers, which have been widely available for many years [15] and now have a global production capacity of about six billion pounds, are synthetic fibers whose polymeric chains are formed by a succession of monomeric units composed of predominantly acrylonitrile. The U.S. Federal Trade Commission defines fibers containing more than 85% acrylonitrile in weight as acrylic fibers [15]. These fibers are highly resistant to water, chemicals, heat, and ultraviolet light, and are available in staple or in slightly fibrillated form. They have been used in a number of nonwoven products, leading to the provision of unique properties [16].

An older study reported that synthetic fibers can act as an effective adsorbent of stickies in papermaking systems [17]. It was reported that the addition of synthetic fibers with a high surface area at a lower level can wrap and pacify sticky particles and thus prevent agglomeration and minimize deposits in the paper machine system. Although this method has been shown to be effective, no recent reports indicating the application of the previously mentioned method have been presented [6]. The cost and the inability of most synthetic fibers to bond with natural cellulose fibers are the two essential factors that discourage the application of synthetic fibers in conventional papermaking [12].

The aim of this research is to investigate the effects of adding acrylic fibers for the control of stickies during papermaking operations and as a way to enhance the properties of the produced sheets. Differing from most previous studies, in this work the acrylic fibers were added directly to the OCC fiber suspension, such as to enable the interaction between their surfaces and suspended matter in the mixture, and a portion of those fibers were subsequently removed by screening of the pulp. In a future implementation of this technology, some of the acrylic fibers would likely be rejected in a screening operation during upgrading of the recovered fiber slurry, thus providing an opportunity for removal of stickies and other oleophilic matter from the system. The remainder of the acrylic fibers would then proceed forward through the papermaking process, where they would presumably influence such properties as apparent density, tensile strength, and resistance to burst stresses.

Properties	Amount (Qualitative & Quantitative)
Appearance	Milky White Light
Type	Non - Crosslinking
Emulsifying system	Anionic - Nonionic
Solids, %	59±1
pH (as packed)	6-8
Tg, °C	-35
Viscosity, cP	≤5000
Mechanical Stability	Good

I. Specifications of initial acrylic water base pressure sensitive adhesive (manufacturer brochure).

MATERIAL AND METHODS

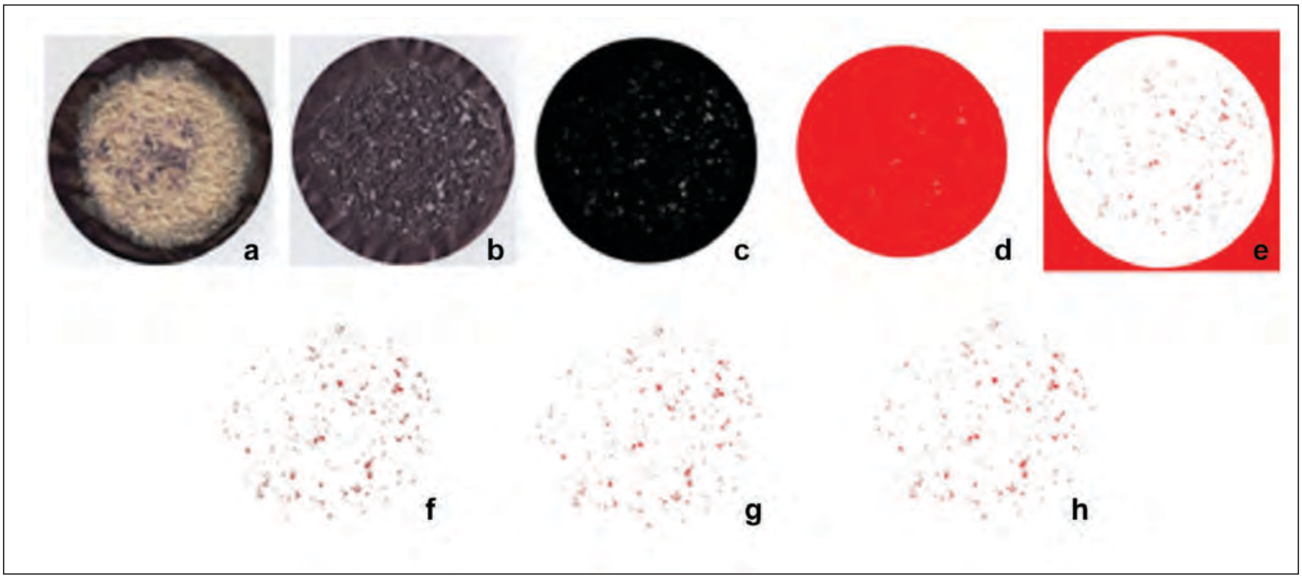
Raw material

Old corrugated container (OCC) pieces were randomly collected from post-consumer waste. The water-based acrylic PSA was purchased from a national company (Simab Resin; Tehran, Iran). Some of its specifications are shown in **Table I**.

A rod coater at a rod speed of 70 mm/s was used to apply a coating of PSA to a piece of silicon paper in order to obtain a coating weighing 27 g/m^2. This was then dried in an oven at 50°C for 1 h. The dried PSA resin film was pressed onto OCC sheet samples at 10% weight ratio.

The scavenger material, intended to collect and passivate oleophilic matter from the suspension, consisted of industrial

1. Microstickies deposition tester and its propellers.



2. The various stages in the processing of the scanned image of the macrostickies pads in ImageJ: a = initial pad scan, b = dyed pad, c = binary of image, d = threshold image, e = inversion of images, f = clear outsides, g = closed particle environment, h = filled holes (final image for analysis).

textile acrylic fibers purchased from Montefibre Hispania (Barcelona, Spain) with the trademarked name of Leacril fiocco. The original fibers were cut to the selected length (approximately 2 mm) by scissors.

Repulping

The prepared OCC material was presoaked in the water bath for 2 h and then repulped with 5% consistency and at the 50°C and 10000 revolutions of disintegration. The resulting suspension was used in the subsequent steps.

Microstickies

Microstickies were measured in accordance with the Doshi method using the locally made apparatus shown in **Fig. 1** [18]. In this method, two parallel stainless steel paddles hold two 12.7 cm by 2.54 cm high density polyethylene (HDPE) films rotating at a speed of 100 revolutions per minute inside 12 L of drained water containing microstickies at 65°C for 30 min. At the end of this period, the HDPE was removed from the frame and rinsed with deionized water with a temperature of 20°C, dried to a constant weight at 105°C, and finally weighed.

Turbidity measurement

The filtrate collected from slot screening of OCC pulp was left to settle for 24 h, and its turbidity was then measured using a Wagtech turbidity meter (Wagtech Projects; Thatcham, UK) [3,4].

Macrostickies

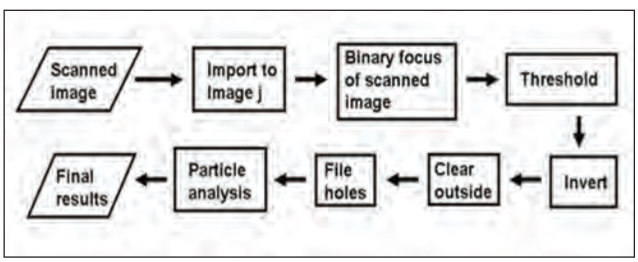
Macrostickies were measured according to TAPPI Standard Test Method T 277 pm-99 "Macro stickies content in pulp: the 'pick-up' method." The bone-dry pad of macrostickies was weighed, and the contents were reported as a percentage of macrostickies.

Image analysis of macrostickies

Figure 2 shows photographs of the stickies on their filter pads, at various stages of processing. The scanned image of the macrostickies pad at the highest resolution (600 dpi) of an LIDE 200 Canon scanner (Canon; Tokyo, Japan) was then analyzed with open source ImageJ software according to the processing steps shown in **Fig. 3**.

The properties of handsheets

Handsheets were prepared according to TAPPI Standard Test Method T 205 sp-02 "Forming handsheets for physical tests of pulp" with a basis weight of 130±5 g/m^2, and their physical, optical, and mechanical properties were tested according to the following TAPPI Standard Test Methods: conditioning (T 402 sp-03 "Standard conditioning and testing atmospheres for paper, board, pulp handsheets, and related products"), brightness (T 452 om-02 "Brightness of pulp, paper and paperboard [directional reflectance at 457 Nm]"), caliper thickness (T 411 om-05 "Thickness [caliper] of paper, paperboard, and combined board"), tensile strength (T 494 om-01 "Tensile properties of paper and paperboard [using constant rate of elongation apparatus]"), burst strength (T 403 om-02 "Bursting strength of paper"), tear strength (T 414 om-04 "In-



3. Flow chart of image analyzing method with Image J.

ternal tearing resistance of paper [Elmendorf-type method]"), and air resistance (T 460 om-02 "Air resistance of paper [Gurley method]").

SEM images

Scanning electron microscopy (SEM) images were prepared using a LEO 1450 VP microscope (Carl Zeiss; Oberkochen, Germany), with resolution 2.5 nm equipped with EDS sensor model 7353. The samples were coated with gold and palladium before imaging.

Statistical analysis

The results were analyzed with the standard pairwise t-tests. To simplify the comparison of means, error bars with 95% confidence intervals are provided in all the figures. The following formula and the corresponding t table were used for this purpose [19,20].

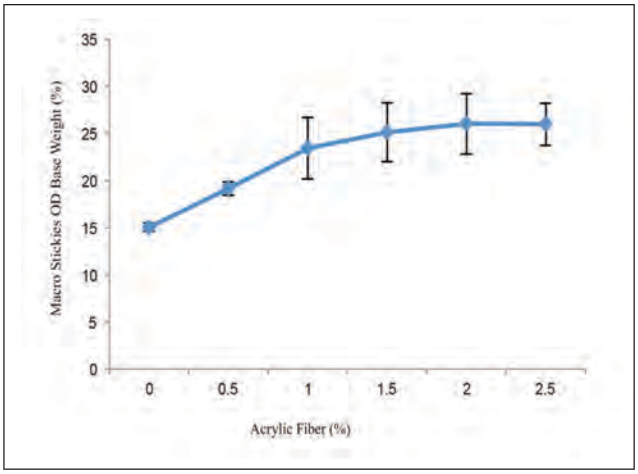
Error Bar (95% Confidence Interval) $= M \pm (t_{(n-1)} \times SE)$

where:
SE = standard error
M = mean
N = sample size

RESULTS AND DISCUSSION

Macrostickies

Figure 4 shows the impact of acrylic fiber on the relative weight of the macrostickies. The use of acrylic fibers up to 1.5% led to an increase in the weight of macrostickies. However, application of higher levels of acrylic fiber was not deemed to be significantly different relative to the 1.5% level of acrylic fiber at the 95% confidence level. After attachment to the stickies, elongated acrylic fibers seemed to result in formation of larger particles of stickies and their agglomeration. The inability of natural and synthetic fibers to pass through Somerville screen slots resulted in the increase in the weight of the collected macrostickies.



4. Impact of acrylic fiber on the weight of screened macrostickies with different treatment dosages.

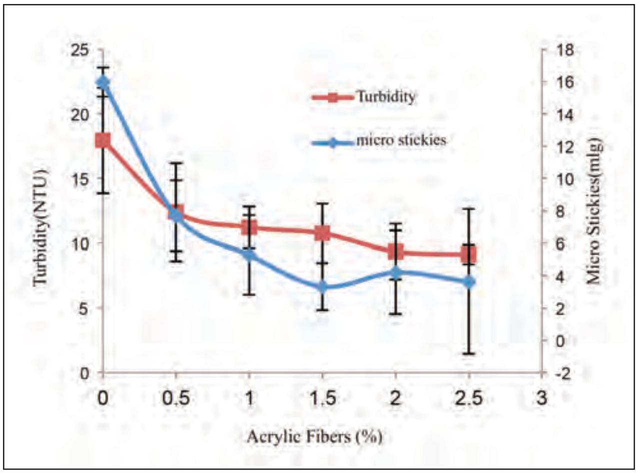
Image analyses of macrostickies

Table II summarizes results for the analysis of macrostickes, as affected by optional addition of acrylic fibers followed by screening. As the results indicate, addition of acrylic fibers was directly related to the number, area, and logarithmic area density of the stickies. Addition of different levels of acrylic

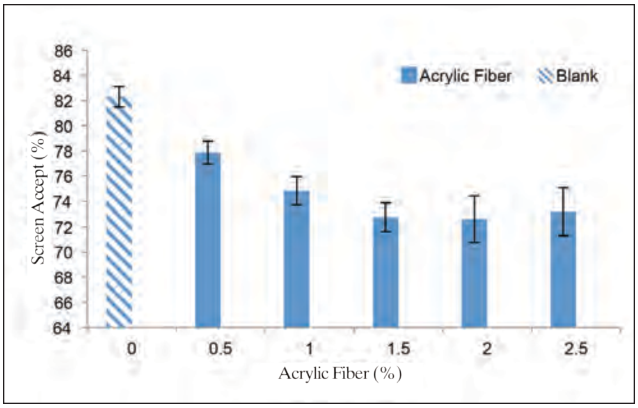
Class Size	Diameter Range of Stickies, µm	Control			Acrylic Fiber 1.0%			Acrylic Fiber 1.5%			Acrylic Fiber 2.5%		
		C	A	D	C	A	D	C	A	D	C	A	D
1	100 - 200	51	6.6	2304.1	28	3.37	1164.16	2431	3.92	1354.16	25	4.50	1582.16
2	200-300	36	8.6	2418.4	29	6.17	1776.18	32	8.16	2349.06	26	6.75	1943.15
3	300-400	18	6.6	1786.7	13	4.66	1252.06	16	5.03	1351.47	15	4.63	1244
4	402-500	21	9.5	2466.5	29	13.01	3370.72	31	14.09	3650.54	34	15.39	3987.35
5	500-600	20	11.0	2804.3	23	10.79	2733.43	25	13.84	3506.08	28	14.48	3668.21
6	600-700	27	17.0	4258.0	21	13.33	3325.72	23	14.98	3737.38	24	15.24	3802.25
7	700-1000	22	16.2	4538.7	28	21.19	5925.78	28	23.66	6615.51	32	23.76	6644.48
8	1000-2000	19	23.3	10061.2	32	34.81	15031.29	34	38.23	16508.19	39	42.77	18468.62
9	2000-5000	16	41.1	36854.3	26	57.40	51417.03	29	64.11	57417.62	31	71.98	64466.08
10	>5000	14	89.9	51777.1	25	147.82	85107.36	27	151.55	87254.91	29	152.60	87859.45
		244	**229.8**	**119332.3**	**254**	**312.55**	**17103.8**	**269**	**273.46**	**183745.9**	**283**	**352.1**	**193665.8**

C= number of stickies measured; A= measured area of stickies (mm^2); D= logarithmic area density (mm^2).

II. Complete summary of ImageJ analysis of macrostickies.



5. Microstickies content and turbidity of filtrate versus acrylic fiber addition level.



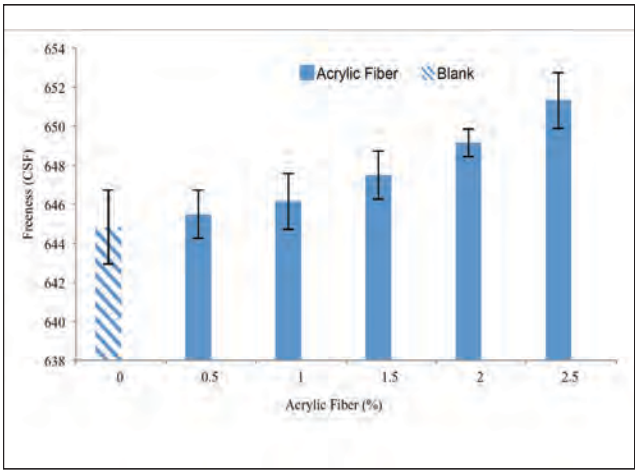
6. Screen accept properties of treated pulp.

fiber maintained a slight increase in the total number and area of the macrostickies. When compared with the control sample, significant change was noticeable in the number and area of stickies within different class sizes. In samples treated with acrylic fibers, an increase in fiber content was detected despite the obvious reduction in the number of macrostickies. The surface area of stickies and their calculated logarithmic area density rose when compared to the control samples.

When acrylic fibers were added to furnish, the number and area of macrostickies in the first two class sizes were considerably reduced, whereas an increase in the same parameters was prevalent in the last four class sizes. The trend of change in fact accrued with class size; i.e., an increase in the addition of acrylic fibers to pulp resulted in the reduction in the number of stickies in the 100-200 and 200-300 class sizes, while the opposite occurred in the other class sizes. It seems that the adherence of acrylic fibers to the PSAs prevented further dispersion and reduced the production of smaller sticky particles in the suspension.

Microstickies

The measurement of microstickies was based on a laboratory arrangement that aimed to simulate the real deposition phe-



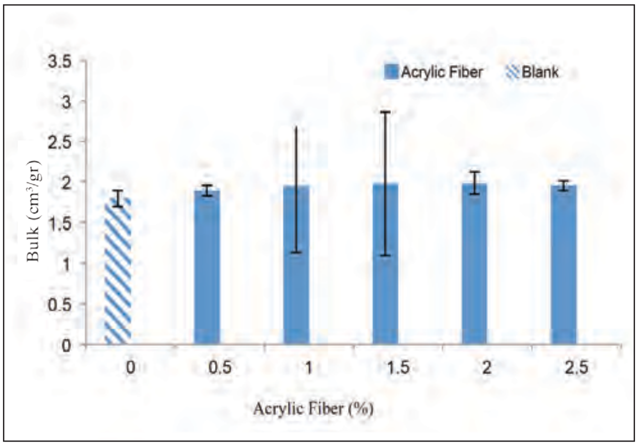
7. Freeness content of treated pulp.

nomena that occur in wet or dry sections of the paper machine [4]. **Figure 5** shows microstickies properties at different treatment dosages of acrylic fibers. These results indicated that the addition of synthetic fibers was the main reason for the reduction of deposited microstickies and that stickies were attached to the surfaces of the synthetic fibers. It has been suggested that the sticky substances can be adsorbed or wrapped by acrylic fibers, thus reducing their tackiness and making them easier to remain in a paper sheet [21]. Therefore, the free tacky particles (i.e., the amount of adhered particles to the deposition tester paddles), decreased, as shown in Fig. 5.

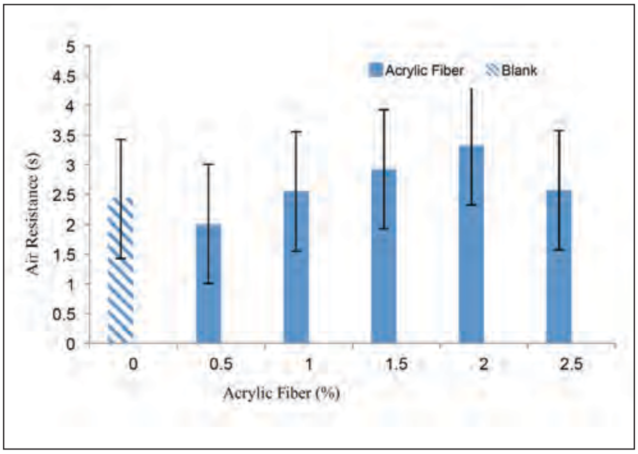
Figure 5 also gives results from the water turbidity analysis of the filtrate that passed through a slotted screen. The results show a substantial turbidity decrease with up to 1% addition of acrylic fibers. It seems that the use of up to 1.5% acrylic fiber resulted in maximum collection of microstickies so that there were less suspended particles in the drained water. Increasing the use of acrylic fibers from 2% did not have a considerable effect. Use of a higher percentage of acrylic fiber was not effective for the further reduction of microsickies.

Screen-accepted pulp amounts using different acrylic fiber addition levels are shown in **Fig. 6.** According to these results, an increase in acrylic fibers resulted in the reduction of the acceptable amount of pulp. In fact, the attachment of stickies particles to acrylic fibers yielded larger objects (acting like macrostickies) that could not pass through screen slots. As a result, the amounts rejected, or the increase in macrostickies, can explain the decrease in the final screen acceptable pulp amount.

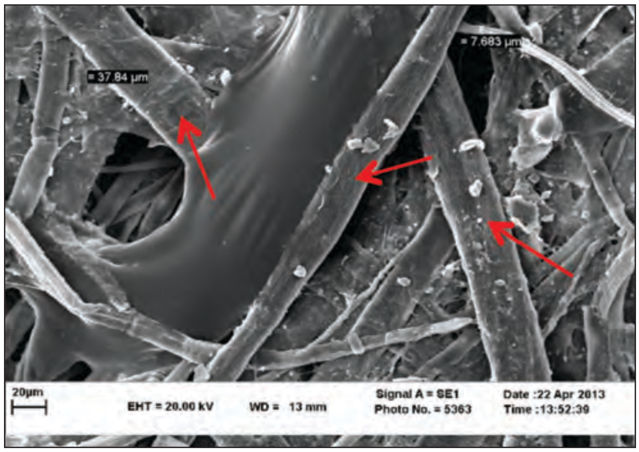
The freeness values of recycled pulp with added acrylic fibers are shown in **Fig. 7**. As can be seen, the addition of acrylic fibers increased the freeness of the obtained furnish. One way to account for such an effect is that the acrylic fibers have no natural affinity for water absorption. Furthermore, they significantly improved pulp freeness by the agglomeration of microstickies, which otherwise might tend to clog channels in the wet web of paper during dewatering [22]. The



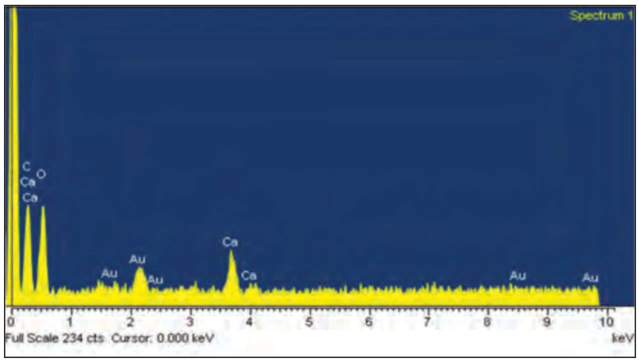
8. Bulk properties of handsheets.



9. The effects of acrylic fiber addition to pulp suspension on air resistance of handsheets.



10. Micrographs of PSA surface that was treated with acrylic fibers. An arrow shows where an acrylic fiber is partly covering a large flake of PSA present in the sheet.



11. Elemental analysis of particles on the treated PSA with acrylic fibers.

acrylic fibers can also be expected to provide a bulkier, more porous wet mat of fibers during formation of the sheet. All three of these factors can be expected to favor more rapid release of water from the wet web.

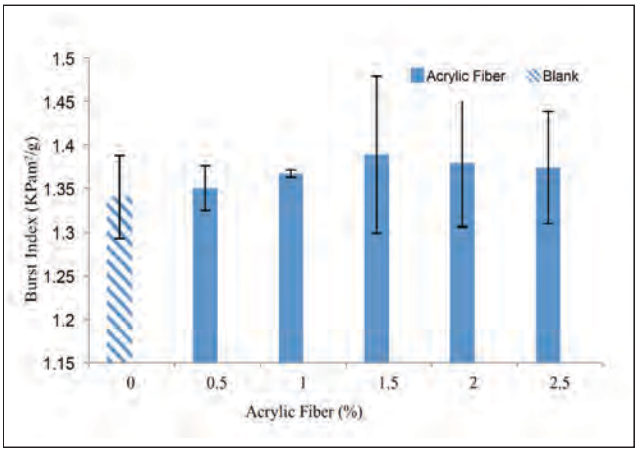
A change in bulk (the reciprocal of apparent density) with the addition of acrylic fibers can be seen in **Fig. 8**. It can be seen that the bulk of handsheets increased from 1.79 for the control condition to 1.98 cm^3/g (10.61%) at an addition level of 2% acrylic fiber. One of the important reasons for this increase is the weaker bonding between acrylic and natural fibers in comparison to the bonding between two natural recycled fibers. Another reason for this is the non-collapsible nature of synthetic fibers, which tends to make the paper thicker. It can be seen in Fig. 6 that addition of more than 0.5% (base on bone dry weight of pulp) of acrylic fibers significantly increased the bulk of the final handsheets.

As can be seen in **Fig. 9**, the effect of acrylic fiber addition on the air resistance of handsheets was not significant; i.e., 100 ml air passed through the handsheets in about 3 s. The treated handsheets showed no significant changes when compared with the blank sample.

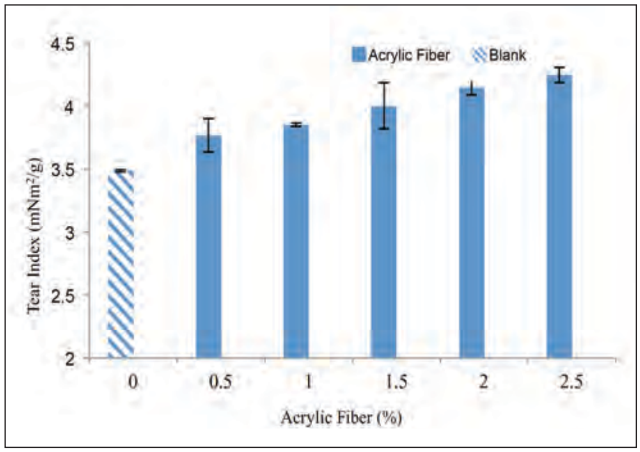
Stickies particles embedded on the surface of acrylic fibers were clearly apparent in the SEM images. **Figure 10** clearly shows sticky particles adsorbed on the surface of the acrylic fibers following agitation.

Figure 11 shows an EDS graph of treated pressure sensitive adhesives with acrylic fibers. This spectrum shows that the calcium carbonate and the gold coating used in preparation of the sample for SEM imaging are the materials prevalent in the sample.

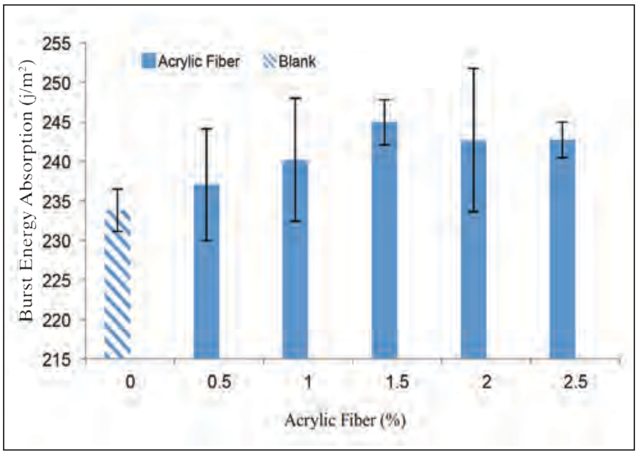
The effects of the addition of acrylic fibers to recycled fibers and the mechanical and physical properties of paper were also investigated. **Figure 12** shows the effect of acrylic fiber addition to pulp suspension on the burst index of the handsheets. It can be seen that the addition of up to 1.5% acrylic fibers led to an increase in the burst strength. The bonding between acrylic fibers and natural fibers is weaker than the bonding between two natural fibers [12]. However, because of the agglomeration of microstickies by acrylic fibers and the consequent cleaning of natural fiber surfaces, the extent of hydrogen bonding between the natural fibers will increase. Also, it is likely that the relatively long synthetic fibers will contribute to greater strength. Results showed that using greater amounts of acrylic fiber can improve the mechanical properties of paper such as burst index and burst energy absorption in comparison with the control sample (Fig. 12 and **Fig. 13**).



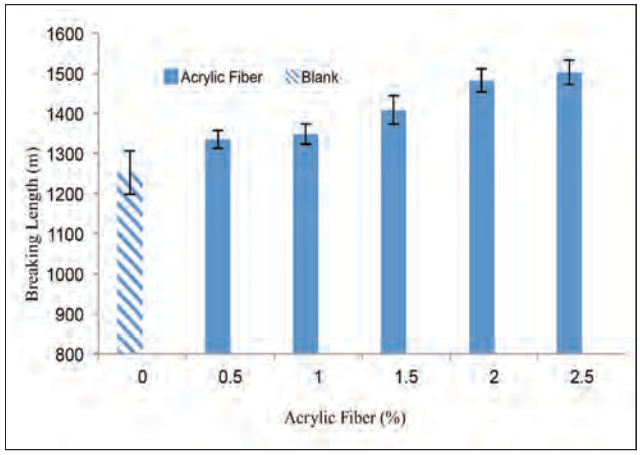
12. The effects of acrylic fiber addition on pulp suspension on the burst index of the handsheets.



14. The effects of acrylic fiber addition to pulp suspension on tear index of handsheets.



13. The effects of acrylic fiber addition on pulp suspension on burst energy absorption of the handsheets.



15. Effects of acrylic fiber addition to pulp suspension on the breaking length of handsheets.

Generally, addition of acrylic fiber to low quality OCC recycled fibers improves the tear strength of paper [13]. The basic properties of acrylic fiber, such as greater length, strength, and stiffness, are the most important reasons for improving the tear strength (**Fig. 14**). The synthetic fibers like acrylic fibers, among the natural ones, act as reinforcing rods and improve the strength properties of the resultant paper [12].

Breaking length, as one of the most important properties of paper, depends principally on the effective number of bonding sites (hydrogen bonds) available on the fiber surface and on the strength of single fiber [23]. Therefore, resistance is improved by increasing the usage of acrylic fibers. **Figure 15** indicates the significant improvement in the breaking length of handsheets by the addition of acrylic fibers to OCC pulp.

Practical implications

The results of this study, though showing promise, suggest the need for further experimentation and mill trial work to determine the best implementation strategies. A key area of concern lies in whether or not it will be advantageous to incorporate substantial quantities of plastic fibers in the selected paper product. Though the present work suggests a range of possible benefits in terms of strength properties, freeness gains during papermaking, and higher caliper at a given basis weight, it will be important to examine the detailed effects of the synthetic fibers on paper product performance in different end uses. While it is reasonable to suppose that sticky particles adsorbed onto the surfaces of synthetic fibers within a sheet of paper will be so small and well incorporated into the sheet as to not cause problems during converting and usage of a paper product, this assumption would need to be checked in each case.

An alternative approach to future implementation of the technology demonstrated in the present work may be to optimize the system such that essentially all of the synthetic fibers are removed from the system by screening. The present work shows that addition of acrylic fibers to the fiber furnish as a whole was a promising option, leading to effective collection of stickies from the suspension. By prudent selection of the length and other properties of such fibers, it seems likely that a system can be optimized to allow semi-quantitative removal of the synthetic fibers, together with their load of adsorbed stickies, from the system. Depending on how the recovered fiber processing operations are set up, it might also be possible to clarify the process water in a paper recycling plant by mixing fiber-free process water with synthetic fibers, followed by screening, as a means of purging stickies from the system. The relative value of such processing would need to be weighed against the cost of materials, also noting that such an approach would not be benefiting from any possible contribution of the synthetic fiber inclusion in the paper product.

CONCLUSIONS

This investigation used commercially available suspension of model PSA stickies in a laboratory system to determine the adsorption, wrapping, and pacification of sticky particles onto acrylic fibers. The results showed that the use of acrylic fibers can effectively change the macro- and microstickies ratio in recycled pulp and improve freeness of treated pulp. Results confirmed that the use of acrylic fibers for control of stickies can promote the mechanical strength properties of the final handsheets. Thus, a case can be made for further work in which synthetic fibers are incorporated into the processing of recovered fibers with the aim of achieving a combination of benefits, the passivation of stickies, the possible increase of production rates, and the improvement of key paper properties. **TJ**

ACKNOWLEDGEMENTS

We gratefully acknowledge the financial support provided by the Iran National Science Foundation (INSF) for the financial supports (Grant No. 90003557) and the Gorgan University of agricultural sciences and natural resources, as Ph.D. thesis supports. We also thank Dr. Alireza Shakeri for his kind advice in the different steps of this research.

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ABOUT THE AUTHORS

Stickies represent a key problem in paper recycling. According to our research, there is the potential to overcome this problem and to solve many technical difficulties during the production process at mills. Previous research from our group focused on deinking of recycling papers, and the present work is focused on removing other important impurities in recycling fiber lines.

The greatest challenges in this research were associated with pressure-sensitive adhesives (PSAs), as they have permanent, sticky properties. We did discover that physical control of PSAs led to improvement in some strength properties of paper. This physical control of sticky materials is one of the potential methods for control of stickies that could become more widely used in the future.

Other methods, such as biological methods using enzymes for control of stickies, are the next project for our research group.

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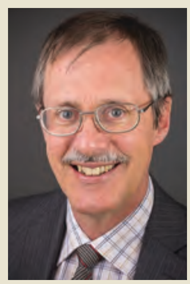
Ghasemian

Resalati



Hubbe

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