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IMPROVING THE FINES PERFORMANCE OF RECYCLED PULPS

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ABSTRACT

This paper considers the impact of fines on the papermaking potential of recycled pulps, and reports on our progress to improve the performance of the fines fraction of recycled pulps.

The papermaking performance of recycled pulps can be adversely affected by such factors as hornification, contamination, loss of bonding potential, aging, and fiber damage. The impact of these factors on the fines fraction is quite severe, and as a result, they are only regarded as a filler material. Strategies to improve the papermaking potential of recycled pulps include fractionation where the fines are either discarded or later recombined with the refined long fiber fraction; and caustic treatment of the whole pulp particularly old corrugated containers (OCC).

In the work reported here, fractionation is used to separate out the fines fraction (i.e., material passing a 200-mesh screen). The impact of sodium hydroxide treatment on drainage behavior and paper properties of blends of treated fines and the long fiber fraction are presented.

KEYWORDS
Fines, sodium hydroxide, caustic, refining, fractionation, hornification,

INTRODUCTION

Increasing recycled fiber utilization and reducing solid waste and energy consumption are extremely important goals mandated for the United States paper industry. Therefore, we are endeavoring to improve the papermaking performance of recycled fiber, so as to increase usage of this valuable resource as well as to reduce energy consumption.

A recycled pulp differs from a virgin pulp since it can lose some of its papermaking potential through drying, contamination, aging, and fiber damage. These factors need to be considered when examining the papermaking potential of recycled fiber.

It is generally agreed that the fines fraction contributes appreciably to the strength of virgin pulp sheets (1), especially for pulps of thick-walled species such as Southern pine and for mill-refined pulps. However, after drying, their contribution is negligible, and they slow down drainage of the sheet. Although it is well established that recycled fines have little strength, the reasons for their ineffectiveness are unknown, and almost no work has been carried out on the subject.

By fractionation virgin and recycled pulps can be divided into long fiber and fines fractions. We use the generally accepted definition of fines as the pulp fraction which passes through a 200-mesh screen.

Fines material can be further categorized depending on pulp type, i.e., mechanical, chemical, virgin, or recycled. The properties of fines will also depend on where they originate. The definitions given in Table I will be used in our discussion of fines.

Table I demonstrates that keeping track of fines can be a complex undertaking. As an example the fines present in twice dried refined pulp F_2 consist of:

$$F_2 = P_{0d2} + S_{0d2} + S_{1d1} + S_2$$

The primary fines P_0 present in a virgin pulp prior to refining consist mainly of ray and parenchyma cells, and represent around one to eight percent of the furnish. They are regarded as filler material and do not contribute significantly to paper properties (2). On the other hand secondary fines S_0 do contribute positively to many paper properties, although they do have an adverse effect on drainage and water removal (2)(3).

The fines present in a once dried pulp consist of a portion

of dried primary fines P_{0d1}, and dried secondary fines S_{0d1}. These fines, which are the main focus of this paper, tend to perform like primary P fines, i.e., as a filler material. On the other hand, the secondary fines S_1, produced by refining a once dried pulp, tend to equal or better the performance of virgin secondary fines S_0 (3)(4).

We propose that fractionation of a recycled pulp will enable a more appropriate treatment for the long fiber and fines fractions. Treatment of the long fiber fraction will probably involve some level of refining and possibly chemical treatment to reverse the effects of drying and to remove defects, while minimizing fiber damage and fines production. This strategy has been suggested by Musselmann (5) as a way to reduced energy consumption.

In many instances recycling does involve fractionation, but the fines fraction (P_{0d1} + S_{0d1}) of the pulp is disposed off, and a portion of the long fiber fraction is also lost. When deinking is involved, in addition to fines, filler, ink particles, and other contaminants are also disposed off as solid waste. **However, one of our goals is to recover the papermaking potential of the fines fraction S_{0d1} in order to make fractionation a more efficient process and reduce material currently going to landfill.**

One of the main factors contributing to the loss in papermaking potential of a recycled pulp is drying. The effect is known as hornification and results in a loss of swelling of both the long fiber and fines fractions (6) after they have been dried and rewet. Scallan and Laivins (7) have recently shown, using infrared analysis and deuterium exchange, that hornification of a fines free pulp is the result of irreversible hydrogen bond cross links formed between microfibrils during drying, i.e., these bonds are not broken upon rewetting.

Scallan and Tigerstrom (8) in earlier work demonstrated, using predictions of transverse fiber modulus, that hornification of the long fiber fraction can be reversed by refining. They also found no evidence of hornification in pulps above a yield of about 70%. Therefore, very high yield pulps, e.g., mechanical pulps, are not expected to exhibit hornification. Gavelin, Kolmodin, and Treiber (9) found, using critical point drying (cpd), that "hornification" (collapse of structure due to surface tension forces) of mechanical fines could be readily reversed upon rewetting. No similar study has been made of chemical pulp fines.

The mechanism proposed by Scallan and Laivins (7) for hornification of the long fiber fraction might also be presumed to hold for the fines fraction when the pulp yield is less than 70%.

Mancebo and Krokoska (2) found that refining does not reverse fines hornification even though refining does reverse fiber hornification (7). No reasons were given for why this was so, yet this difference is crucial for understanding the ineffectiveness of the fines. This finding might be an indication that other factors in addition to hornification, e.g., agglomeration, changes in wetting behavior, and ineffective communication of mechanical stresses to the fines fraction, might be involved.

It is supposed that some form of chemical and/or mechanical action to impart stresses to the fines will be necessary to reduce agglomeration and reswell the fines. Solute exclusion (10), water retention values (6), and drainage resistance measurements (4) have shown that there is a much higher association of water with the fines than the long fiber fraction. Owing to the smaller dimensions of the fines and surface tension effects, caution has to be exercised when interpreting the extent of fines-water interaction.

It is interesting to note that fines S_1, produced by refining a once dried pulp, are comparable in performance to virgin secondary fines S_0 (3)(4). This implies that drying does not alter the cellulose-water interaction of new surfaces created by refining. However, if changes in crystallinity due to drying occur, as found by Marton et al. (11), this finding may be modified.

There are no theories which satisfactorily account for the contribution of fines to paper properties. In broad terms, we can say that fines contribute positively to the mechanical properties of paper by reducing stress concentration and effectively increasing interfiber bonding (12). There are, according to Page (13), many effects associated with the refining of a pulp, and fines production is one of them. However, we are now considering the treatment of fines themselves which have been dried. As with refining, we will assume that internal and external fibrillation of the fines will be necessary to improve their performance.

The effects of cations, pH, and electrolyte concentration on refining and paper properties have recently been investigated by Scallan and Grignon (14) and Lindstrom and Kolman (15).

Scallan and Grignon have proposed that swelling produced by refining in the presence of electrolytes is due to both mechanical and osmotic stresses. Using fiber saturation point (solute exclusion) as a measure of fiber swelling, monovalent sodium was shown to be the most effective cation in their studies. Furthermore, when kraft and sulfite pulps were acid washed to remove the metal ions present

in the pulp and replaced with sodium ions, the osmotic stress effect was found to be more effective than refining in a PFI mill, i.e., the fibers were internally fibrillated without fines production.

Whether cationic exchange procedures would be effective in reswelling the long fiber and fines fractions of a recycled pulp remains to be determined. In any case, beating under alkaline conditions in the presence of sodium ions, should enhance refining. Lindstrom and Kolman (15) investigated the effects of pH and electrolyte concentration on swelling (water retention value) and paper properties. They were careful to separate out the effects of chemical environment differences during beating and sheetmaking. They found for an unbleached kraft pulp pH=10 is optimum for maximizing swelling, and that the addition of 0.1M NaCl results in a lower water retention value (wrv) at the same beating level of 4000 revs. No similar findings were found for a bleached kraft pulp.

Centola and Borruso (16) in earlier work demonstrated that Congo red has a very significant effect on refining rate and strength development. The mechanism is that suggested by Scallan and Grignon, and the osmotic stress is created by the counterions of the sulfonic acid groups. According to Page (13), other additives which could produce this effect include:

* Sodium carboxy-methyl cellulose
* Oxidized Starch
* Lignosulfonates and modified lignins
* Napthalene, benzene, and stilbene-based dyes
* Hydrolyzed polyacrylonitrile

Page (13) also cautions that fiber-fiber and metal-fiber friction may also be modified by additives. Again, we do not know if such additives would be effective in treating recycled fibers.

Sodium hydroxide is frequently used to treat recycled fiber furnishes, particularly where deinking is involved; however, little information of its effect on refining and strength development has been reported.

An important exception is the study by Freeland and Hrufiord (17), where an OCC furnish (whole) was treated with 2% NaOH for 4 hours. Their data show that there is a rapid rise in compressive strength (which is used as a measure of the effectiveness of the NaOH treatment) over the first hour, and then a more gradual rise over the next 15 hours. The authors suggest that the strength improvement is due to straightening of the fibers with beating. Surprisingly, they found that freeness increases at the same time as sheet density and strength increase.

A more relaxed (no definition given) fiber was suggested as the reason for the higher freeness since the fibers would be less susceptible to damage in this state. We expect that the freeness would be lower with straighter fibers; however, the osmotic stress contribution as proposed by Scallan and Grignon (14) may have resulted in less fines production.

Bovin, Hartler, and Teder (18) found that tensile strength was increased when a kraft pulp was disintegrated in an alkaline solution, but no explanation of this finding was given.

Most of the work which has been done with high levels of caustic treatment of cellulose has been done with cotton. When one examines the changes in cotton fiber properties with caustic treatment, large changes occur close to and beyond 10% NaOH (19). Large losses in hemicellulose and yield are not acceptable, and treatments have to be examined in this light. Freeland and Hrufiord (17) found that the biological oxygen demand increased significantly at 4% NaOH treatment, but was still considerably less than that produced in a Kraft or Sulfite process.

In what follows we report on our initial efforts to improve the fines performance of recycled fiber through fractionation and sodium hydroxide treatment to reverse the adverse effects of drying.

EXPERIMENTAL

The reycled fiber used in this study was a commercial source of old corrugated containers (OCC). This was fractionated using commercial fraction equipment. The Canadian Standard Freeness (CSF) tester was used primarily as an indicator of hydrodynamic specific surface, and because it is a well known pulp drainage test. In addition, the pulp pads from the CSF were wet pressed, and after drying and conditioning used for nondestructive and destructive property measurements.

Fractionation Trials at Black Clawson

Fractionation trials were conducted at Black Clawson's pilot plant facilities by Dr. Jack Firkins. The furnish consisted of 90% corrugated clippings and 10% OCC. Fractionation trials were run at 5000 ft/min with a double nip thickener. The main results of the fractionation trials are summarized in Table II. Under these conditions the fines fraction was 12.4%

Approximately 1.9 lbs, 11.6 lbs, and 4.6 lbs O.D. of the feed, long fiber, and fines fraction, respectively, were sent to IPST. The fines were thickened using a laboratory

centrifuge to a consistency of around 12%.

Long Fiber Fraction Refining and Fines Separation

Secondary fines, i.e., S_1, were generated from the long fiber fraction of the OCC in a PFI mill using 24 gms of dried fiber, and a consistency of 10%, over the range of 0 to 10,000 revolutions. The fines, i.e., S_1, were separated from the long fiber fraction using the TAPPI Britt Jar recommended procedure T261 cm-90.

Sodium Hydroxide Treatment of Fines Fraction

The level of caustic treatment was 0%, 1%, 2%, 4%, 6%, 8%, and 10% Fines were treated at room temperature for 45 minutes, and neutralized to a pH of 7 using H_2SO_4.

Canadian Standard Freeness and Property Measurements

In order to conserve on the amount of fines used and treated, it was decided to try and get more "mileage" out of the CSF measurement. The basic idea is to carefully remove the wet pad from the tester, couch and wet press it, and then dry the pad under full restraint.

The nominal grammage of the CSF pad is 370 g/m^2, and is removed from the tester using a "piston," consisting of a circular metal disk attached to a rod. Prior to removal the pad is gently dewatered by increasing the pressure on the disk. Depending on the freeness, the pad will most times adhere to the metal disk facilitating its removal. After couching the pad is placed between blotters, i.e., two below and one above the pad, and wet pressed for 5 minutes at 50 psi. Prior to couching and wet pressing a synthetic filter disk is placed above and below the disk to avoid sticking to the blotter stock.

The pad is weighed prior to drying to determine its consistency after wet pressing. It is dried between two dryer felts for 15 minutes at a platen temperature of 300°F. Sufficient pressure is applied to the pad during drying to ensure that it is dried under full restraint.

Physical property measurements on the conditioned pads included: grammage, soft platen caliper measurements (20), and in-plane and out-of-plane elastic constant measurements using techniques developed at IPST (21)(22). Compressive strength measurements (STFI) were made following TAPPI recommended procedure T 826.

RESULTS AND DISCUSSION

PFI Refining of the OCC Long Fiber Fraction

The long fiber fraction was refined in a PFI mill over the range of 0 to 10,000 revolutions. The variation of CSF with PFI revolutions is shown in Figure 1 together with the amount of fines produced. There is approximately a linear variation of fines production with PFI revs. Also shown in Figure 1 is the CSF of pulp which has been fractionated at each beating interval, i.e., fines-free. The drop in CSF of the fines free pulp with PFI revs. is attributed to external fibrillation. Hartmann (23) has shown that there is no drop in CSF with internal fibrillation alone, at least as produced by his roll refiner.

Figure 2 shows the variation of CSF with fines content for both secondary S_1 and "primary" ($P_{0d1} + S_{0d1}$) fines. With regard to the secondary fines, we have taken the fines produced at each refining interval shown in Figure 1, i.e., 3000, 5000, and 10,000 revs., and added various percentages of them to the unrefined long fiber fraction. The resulting CSF curve is in close agreement with the original curve indicating, at least for this case, that the fines produced at say 3000 revs. are no different in character from 10,000 revs. as far as CSF is concerned. This is in agreement with the findings of Retulainen, Moss, and Nieminen (1) for never dried pulps.

The curve denoted "primary" ($P_{0d1} + S_{0d1}$) in Figure 2 is derived from the feedstock to the DNP which has a CSF of 517 ml as shown in Table II. Values of CSF were also measured for 15% and 30% addition of the untreated fractionated fines ($P_{0d1} + S_{0d1}$). We note that there is a large difference in the freeness performance of the "primary" and secondary fines, i.e, for a given level of fines addition, the "primary" fines result in a higher freeness than the secondary fines. The difference is attributed primarily to a loss in hydrodynamic surface area of the fines as a result of drying.

Results of Fines Treatment with Sodium Hydroxide 0% to 10%

For each NaOH treatment level, CSF measurements were made on blends containing 15% and 30% fines. The variation of CSF with caustic treatment level is shown in Figure 3. We note that freeness drops initially and then rises to approach the freeness level of the fines-free pulp at 10% NaOH.

This dramatic change in freeness has also been found by Giertz (24) who treated a rayon grade spruce sulfite in 10% NaOH for 3 hours at 120°C. The control pulp and the extracted pulp were refined ultrasonically, and both showed significant external fibrillation. The properties of Giertz's (24) pulps are summarized in Table III.

Giertz (24) suggests that hemicellulose losses are responsible for the above changes. No specific mention is made of changes from cellulose I to cellulose II, or possible changes in fiber cross-sectional geometry, i.e., fibers becoming more circular, which might also be a factor in such a treatment (25).

Using light microscopy, photographs of the untreated OCC fines, and treatment with sodium hydroxide at 2%, 6%, and 10% are shown in Figures 4, 5, 6, and 7. We note that with increasing sodium hydroxide concentration the fines appear to form more compact flocculated structures. It was not possible to break down these structures with a gentle stirring action. Increasing flocculation of the fines with increasing sodium hydroxide concentration might also be responsible for the increase in CSF and other property changes to be discussed.

From a careful accounting of the fines lost to the filtrate in running the freeness test, an estimate of the fines lost from those added is shown in Figure 8. Interestingly, fines loss passes through a maximum at around 1% NaOH treatment level. It is not clear why the fines loss should be the highest at this point, but in view of the minimum in freeness, this might imply that the effective viscosity of the filtrate is increased due to fines loss.

Property measurements on the conditioned CSF pads are shown in Figures 9, 10, 11, and 12. Fines at 15% and 30% addition levels increase apparent density; however, as shown in Figure 9, sodium hydroxide treatment does not appear to significantly affect densification. Furthermore, the dryness of the pad after wet pressing was 44% and unaffected by fines level and sodium hydroxide treatment.

The out-of-plane elastic constant Ez/ρ increases with both fines addition and caustic treatment as shown in Figure 10, whereas the in-plane elastic constant C/ρ rises initially and then decreases with increasing sodium hydroxide level as shown in Figure 11. The changes in elastic properties shown in Figures 10 and 11 may be an indication of changes in cellulose structure, for example, conversion of cellulose I to II and/or changes in fines geometry as illustrated by the flocculated structures shown in Figures 5, 6, and 7. The three-dimensional structure of the flocculated fines is consistent with the increase in out-of-plane elastic constant and the concomittant drop in in-plane elastic constant at high levels of sodium hydroxide treatment.

The variation of short span compressive strength is shown in Figure 12, and the variation is consistent with the elastic property behavior shown in Figures 10 and 11, according to the simplified model of Habeger and Whitsitt (26).

CONCLUSIONS

The Black Clawson double nip thickener is an effective means of fractionating large quantities of pulp, in this case OCC.

The secondary fines S_1 generated by refining the long fiber fraction of OCC have a much larger hydrodynamic surface area than the so-called "primary" fines (P_{0d1} + S_{0d1}) as evidenced by changes in CSF at different levels of fines addition to the unrefined long fiber fraction.

Property measurements made on CSF pads which have been wet pressed and dried show promise as a technique for initial pulp characterization studies.

The treatment of fines with sodium hydroxide in the range of 0% to 10% has a significant effect on CSF, elastic, and strength properties. Freeness passes through a minimum at around 1% NaOH, and then rises to almost equal the freeness of the unrefined long fiber fraction at 10% NaOH. Water removal by wet pressing also appears to be independent of fines and sodium hydroxide levels. For both 15% and 30% fines addition, the in-plane elastic constant increases initially, reaching a maximum around 1% to 2% NaOH, after which it decreases to just below the level of 0% NaOH treatment. Both cellulose structure and changes in fines geometry may be responsible for this behavior.

In future studies, we hope to examine chemimechanical treatment of fines, as well as treatment of the long fiber fraction.

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TABLE I FINES NOMENCLATURE

CYCLE	PRIMARY	"PRIMARY"	"SECONDARY"	SECONDARY
		"Unrefined"		Refined
VIRGIN FINES F_0	P_0	-	-	S_0
ONCE DRIED F_1	-	P_{0d1}	S_{0d1}	S_1
TWICE DRIED F_2	-	P_{0d2}	$S_{0d2} + S_{1d1}$	S_2
THRICE DRIED F_3	-	P_{0d3}	$S_{0d3} + S_{1d2} + S_{2d1}$	S_3

TABLE II BLACK CLAWSON DOUBLE NIP THICKENER FRACTIONATION RESULTS

TYPE	CONSISTENCY %	C.S.F. ml
FEED STOCK	1.15	517
LONG FIBER	12.9	731
FINES (12.4%)	0.16	-

TABLE III EFFECT OF HOT ALKALI EXTRACTION ON PULP PROPERTIES
DATA OF GIERTZ (24)

PROPERTY	CONTROL	10% NaOH EXTRACTED 3hrs @ 120°C
YIELD	40	31
% HEMICELLULOSE	6.9	2.1
°SR	90	19
TENSILE Nm/g	69	19

Pulp: Rayon grade spruce sulfite.

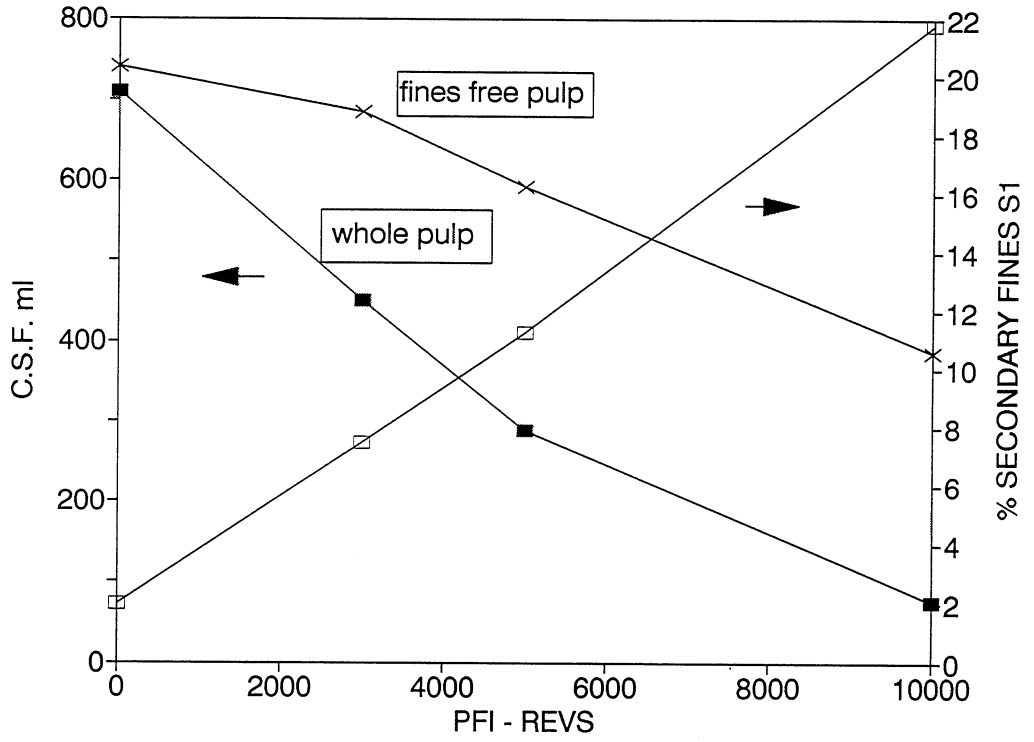

Figure 1 Variation of Canadian Standard Freeness and Fines Content with PFI Revolutions for Refining of Fines-free OCC.

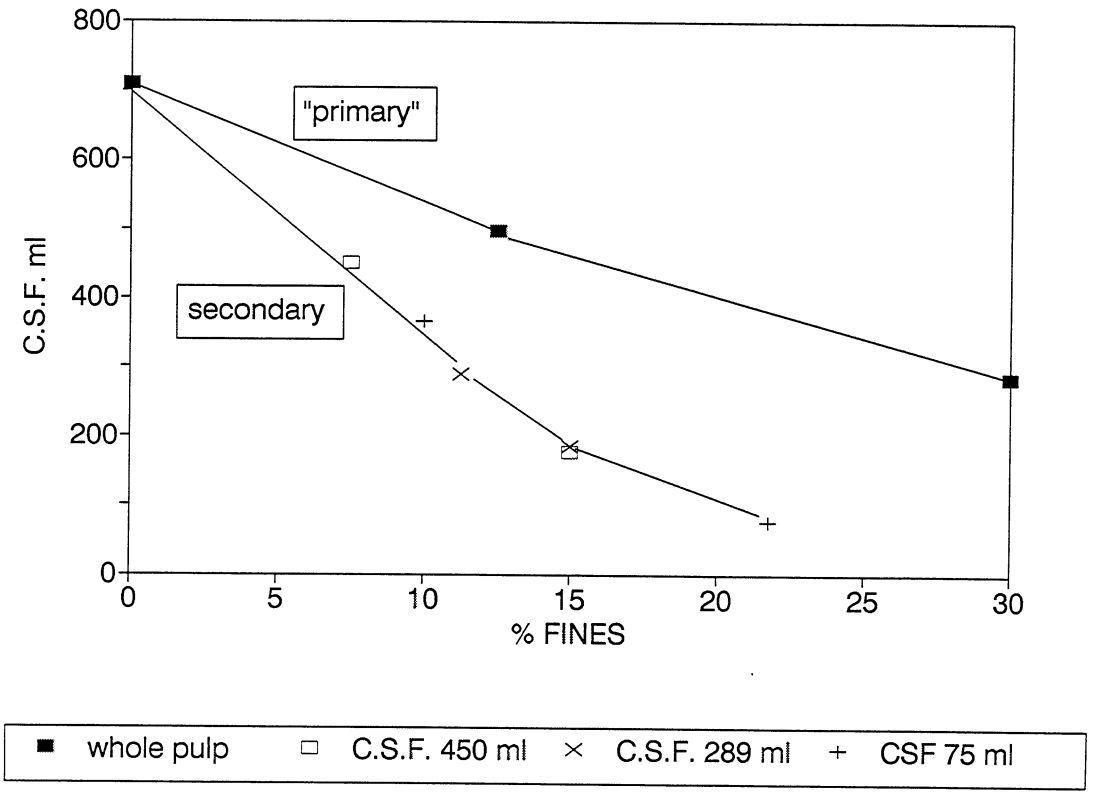

Figure 2 Variation of Canadian Standard Freeness with Fines Content for "Primary" and Secondary Fines.

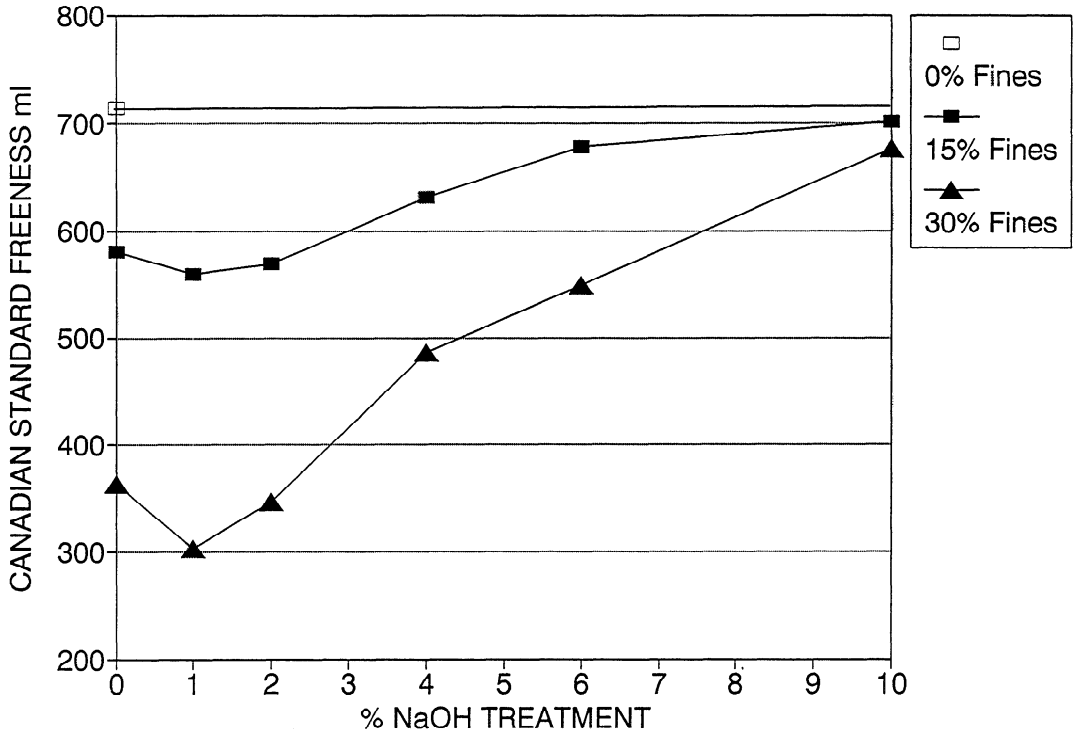

Figure 3 Variation of Canadian Standard Freeness with Sodium Hydroxide Treatment of OCC Fines.

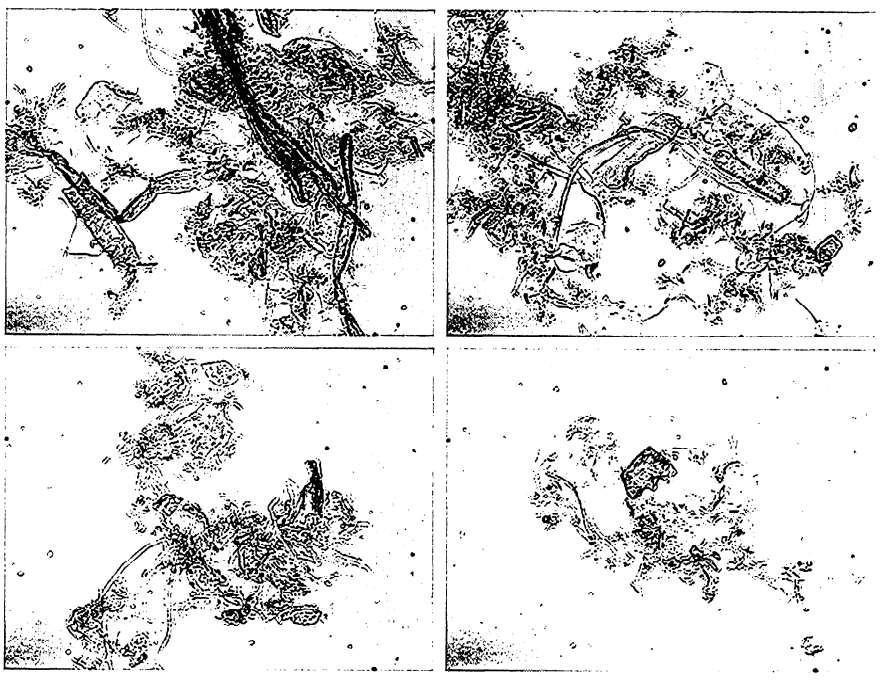

Figure 4 OCC Fines - Control.

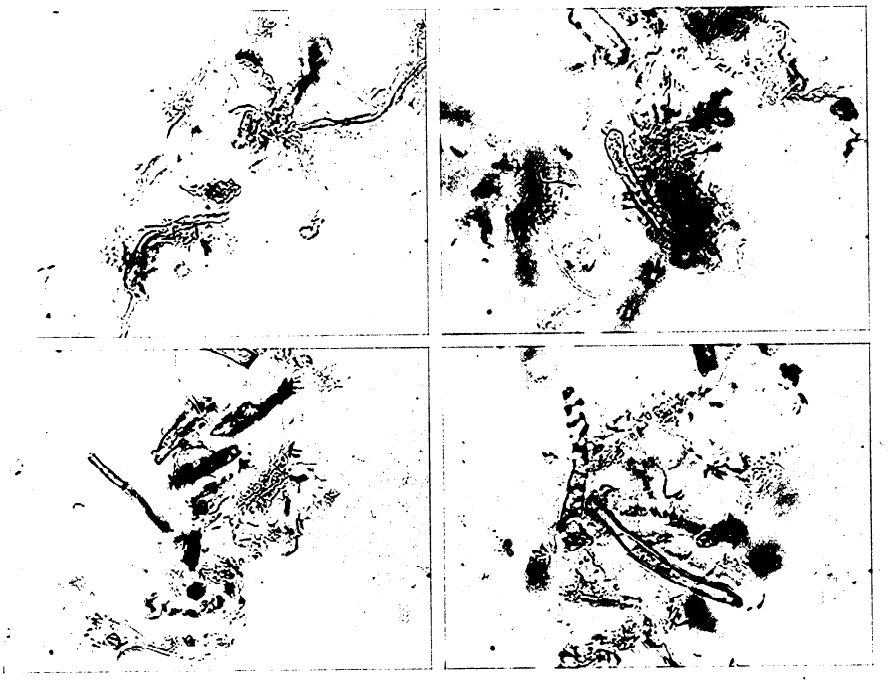

Figure 5 OCC Fines - 2% NaOH Treatment.

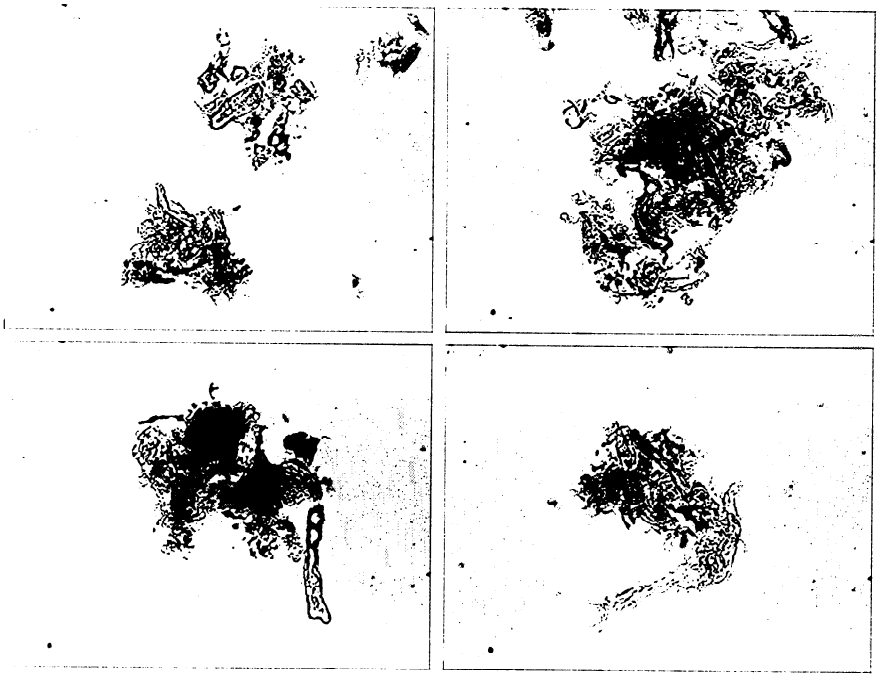

Figure 6 OCC Fines - 6% NaOH Treatment.

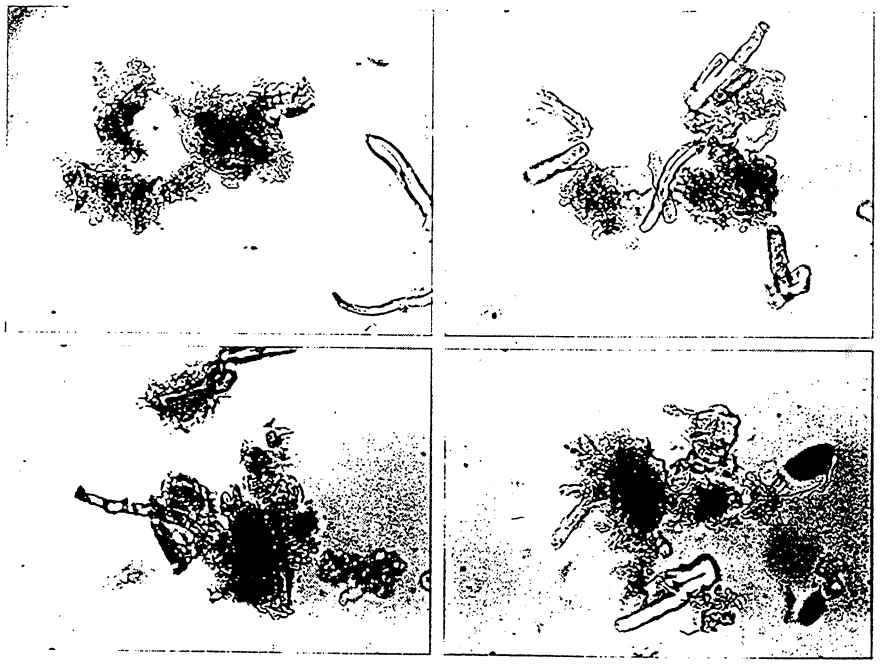

Figure 7 OCC Fines - 10% NaOH Treatment.

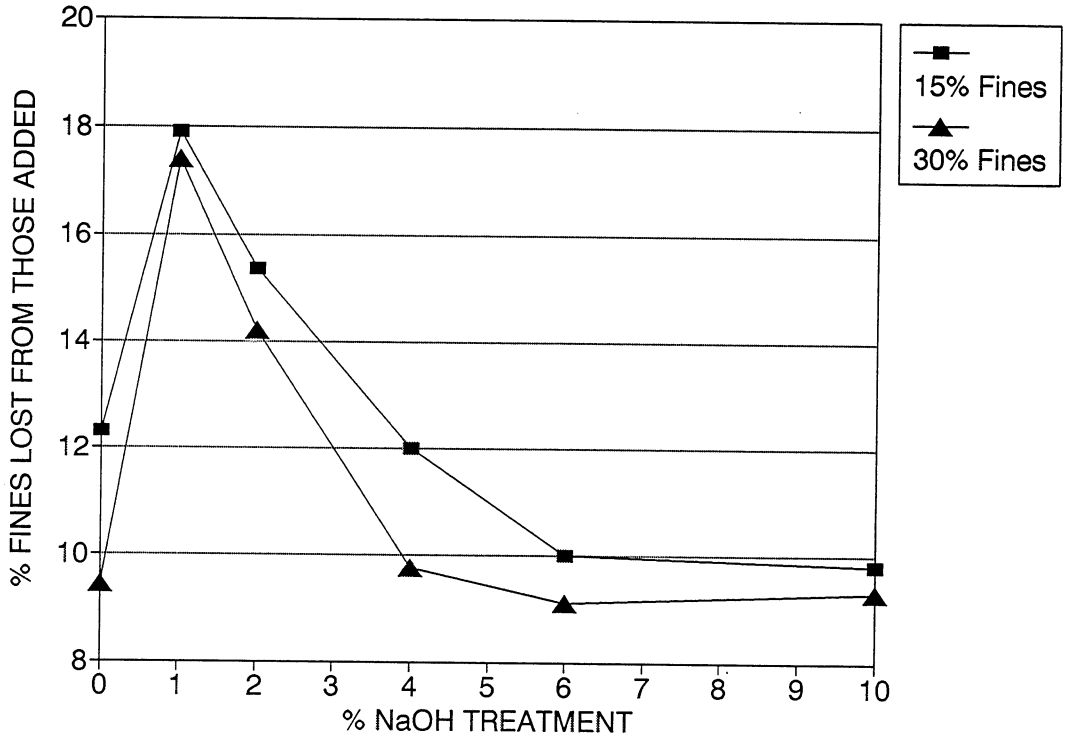

Figure 8 Variation of Fines Lost During Canadian Standard Freeness Test with Sodium Hydroxide Treatment of OCC Fines.

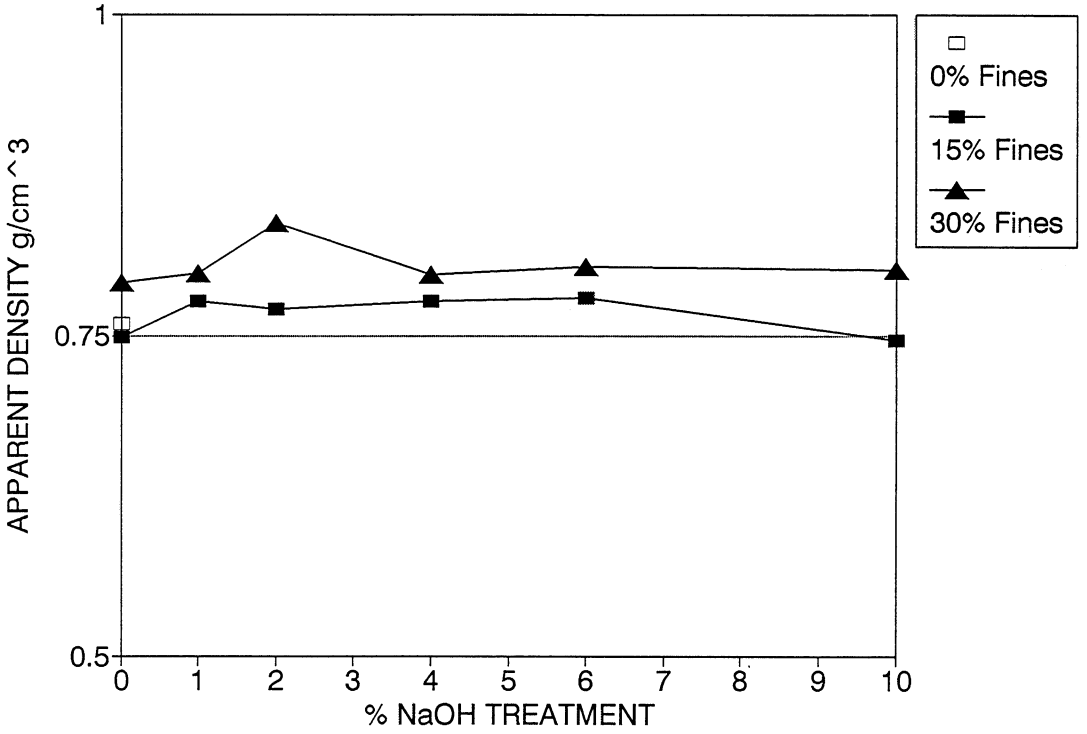

Figure 9 Variation of Apparent Density with Sodium Hydroxide Treatment of OCC Fines.

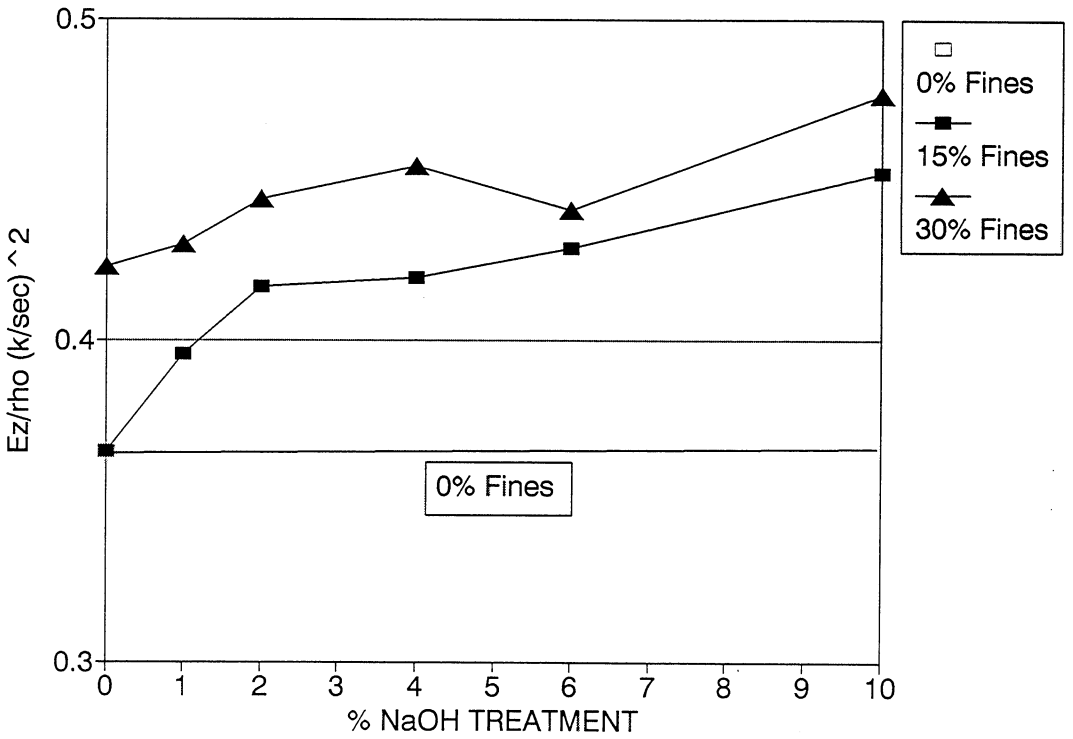

Figure 10 Variation of Out-of-Plane Longitudinal Specific Modulus with Sodium Hydroxide Treatment of OCC Fines.

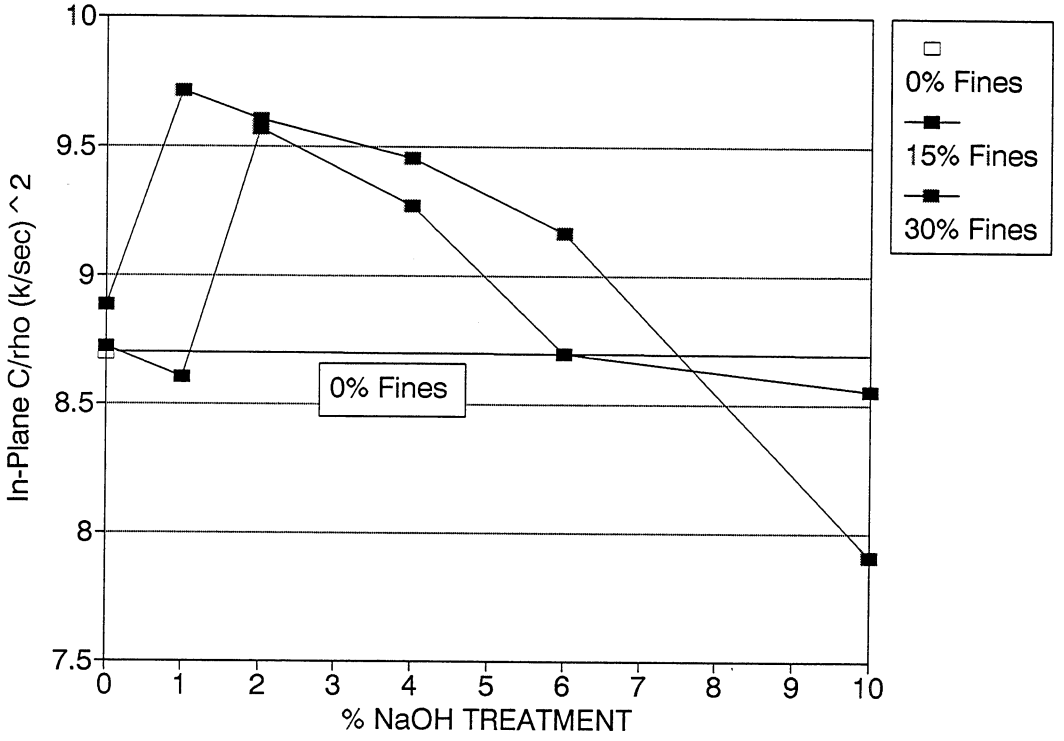

Figure 11 Variation of In-Plane Longitudinal Specific Modulus with Sodium Hydroxide Treatment of OCC Fines.

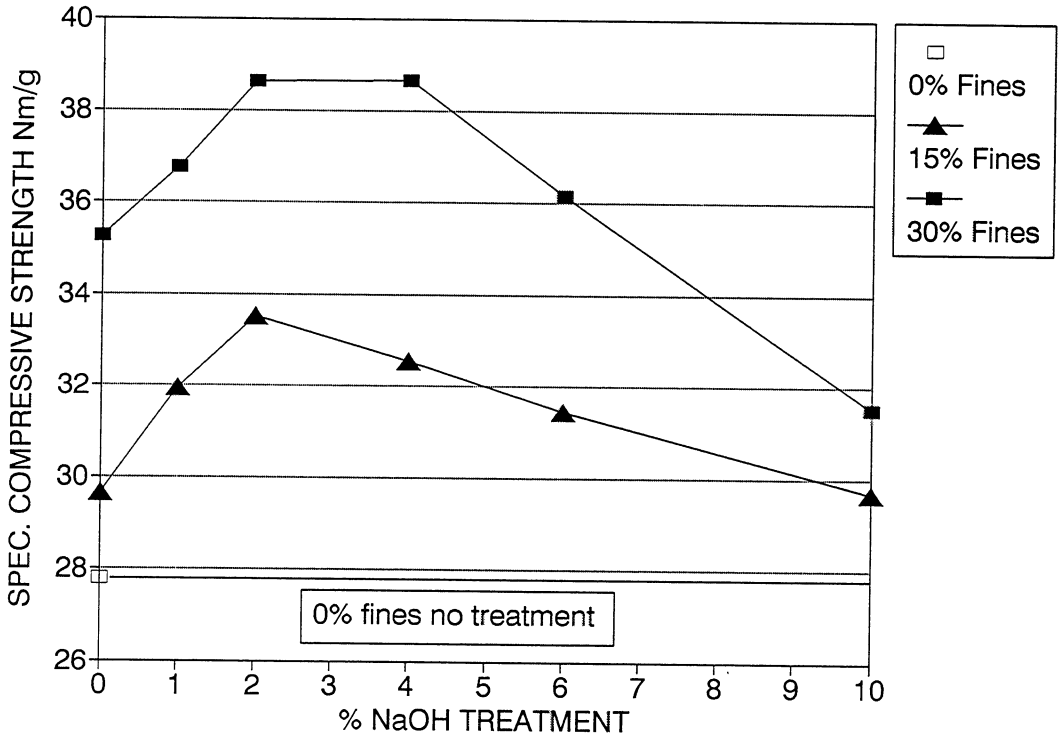

Figure 12 Variation of Specific Compressive Strength with Sodium Hydroxide Treatment of OCC Fines.