KRAFT PULPING OF INDUSTRIAL WOOD WASTE

Aziz Ahmed[1]
Masood Akhtar[1]
Gary C. Myers[1]
Gary M. Scott[2]

[1]USDA Forest Service
Forest Products Laboratory*
One Gifford Pinchot Drive
Madison, WI 53705

[2]Paper Science and Engineering Faculty
State University of New York
College of Environmental Science and Forestry
Syracuse, NY 13210

ABSTRACT

Most of the approximately 25 to 30 million tons of industrial wood waste generated in the United States per year is burned for energy and/or landfilled. In this study, kraft pulp from industrial wood waste was evaluated and compared with softwood (loblolly pine, Douglas-fir) and hardwood (aspen) pulp. Pulp bleachability was also evaluated. Compared to loblolly pine pulp, industrial wood waste pulp needed less cooking time to achieve the same kappa number and achieved a higher pulp yield for a similar kappa number. Industrial wood waste pulp was more effectively bleached than loblolly pine pulp and consumed less chlorine dioxide under similar bleaching conditions. Mechanical properties of paper from industrial wood waste pulp and loblolly pine pulp were very similar except for tear values, which were about two points higher for loblolly pine. Both wood waste and loblolly pine pulps were much stronger than hardwood kraft pulp.

INTRODUCTION

A major problem affecting pulp and paper industries worldwide is the increasing cost of suitable wood fiber resulting from concerns about competing uses for forest lands, environmental impact of forest operations, and sustainable forest management. Both the United States and Canada are major producers of pulp, paper, and paperboard. Despite the increasing use of recycled fiber, the steady increase in worldwide paper and paperboard production is creating a wood fiber shortage for commonly used paper grades [1]. The World Food and Agriculture Organization has forecast an annual increase of paper and paperboard consumption from 210 million tons in 1988 to 350 million tons by the year 2010 [2]. About 20 to 30 million hectares of new forest and fast-growing plantation will be required to meet the demand for wood fiber by paper industries. One possible solution for countries that lack forest resources could be the use of nonwood fibers such as straw, kenaf, jute, bagasse, and flax [3]. The fiber shortage in the forest-rich countries of Canada, the United States, and Scandinavia could be met from using industrial wood waste.

Industrial wood waste consists of manufacturing, construction, and demolition waste as well as wood pallets. About 25 to 30 million tons (oven-dry basis) of this waste are currently available in the United States [4, 5]. Industrial wood waste is a mixture of softwood and hardwood depending on the collection sources, and it has an average dryness of 88% to 90%. This low moisture content gives transportation cost advantage to industrial wood waste compared to fresh wood chips, which contain 40% to 45% moisture. Most industrial wood waste is burned for energy and/or landfilled. It is not suitable for mechanical pulping because of its dark color and species heterogeneity. The kraft pulping process can better handle the wide variety of species and provide a pulp of satisfactory properties.

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The main objective of this study was to verify the suitability of industrial wood waste for kraft pulping and to establish the response of the kraft pulp to conventional elemental chlorine-free bleaching chemicals. The mechanial and optical properties of papers prepared from these pulps were compared with that of papers prepared from kraft pulps from two softwoods and a hardwood widely used in the pulp and paper industries.

MATERIALS AND METHODS

Wood waste is collected from throughout California and processed at Fresno through a screening system to separate metallic parts, nails, plastics, and other noncellulosic materials. Recovered wood waste is chipped and subsequently screened to separate oversize chips, pin chips, and sawdust. Oversize material is rechipped, sawdust is used for animal bedding and/or landfilled, and pin chips are burned for energy or used to manufacture particleboard and medium-density fiberboard (MDF).

A truckload of industrial wood waste pin chips was sent to the Forest Product Laboratory (FPL) for our experimental work. The chips had dryness of 88% to 90%. The chips were placed in a tumbling digester, and kraft white liquors and water were added to achieve a 4:1 liquor-to-wood ratio. Cooking conditions, pulp yield, and kappa number are presented in Table I. After cooking, pulp was washed with 90°C water to prevent separated lignin from condensing on the fiber surface. Pulp was hot-water defibrated for 5000 revolutions in a British disintegrator. The disintegrated pulp was washed by filtration, and pulp yield was measured after washing. Pulp was screened through a laboratory flat screen with 0.203-mm-wide slots; rejects were less than 1% for all pulps. Canadian standard freeness (CSF) of screened pulp ranged from 600 to 650 mL. Each pulp was refined in a PFI mill to three CSF levels. Handsheets were made, and mechanical and optical properties were measured according to TAPPI standard methods.

For comparison, conventional 19-mm wood chips from loblolly pine (*Pinus taeda* L.), aspen (*Populus tremuloides* Michx.), and small-diameter *Douglas-fir* (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) were kraft pulped. The fiber processing procedure was identical for all raw materials.

Pulp was bleached using the DEDP, DEPD, and XDEDP stages. Chlorine dioxide bleaching or caustic extraction of pulp was done in a polyethylene bag containing 15 g (oven-dry) pulp, plus the required chemical and water to provide 10% consistency. Chelation of pulp, before the hydrogen peroxide stage, was done with 0.2% DTPA at 60°C for 2 h at 3% consistency level in a polyethylene bag. For the hydrogen peroxide stage, bleaching chemicals consisted of 1.8% H_2O_2, 1.5% NaOH, 1.5% Na_2SiO_3, and 0.05% $MgSO_4$. Bleaching temperature was maintained by immersing the sealed polyethylene bag containing the pulp and bleaching chemical in a heated water bath. After the hydrogen peroxide stage, pulp was neutralized with sodium bisulfite. Pulp was washed with deionized water after each bleaching stage. For xylanase treatment, 1000 AXU or 500 AXU (xylanase unit) per kilogram of oven-dry pulp was used. Pulp was mixed with xylanase solution in a polyethylene bag to achieve 10% consistency and heated at 60°C for 2 h in a heated water bath. Pulp was then washed with deionized water, followed by an extraction stage with 2% NaOH. Bleaching conditions and consumption of bleaching chemicals are given in Table II.

Table I. Kraft pulping conditions, yield, and kappa number for industrial wood waste and other materials[a]

Raw material	Active alkali (%)	Sulfidity (%)	Cooking time (min)	Cooking temp (°C)	Yield (%)	Kappa number
Wood waste	20	25	60	171	44.5	24.2
Aspen	20	25	60	171	51	17.0
Loblolly pine	20	25	75	171	43.3	30.7
Douglas fir	20	25	60	171	48.5	23.2

[a]Ramp time = 60 min; 1iquor: wood ratio = 4: 1.

Table II. Bleaching conditions and chemical consumption for pulp from industrial wood waste, loblolly pine, and aspen[a]

Sample	Bleaching conditions			Consumption of bleaching chemicals (%)				
	Sequence[b]	Time (min)	Temp (°C)	ClO_2 D_1 stage	NaOH E_1 stage	ClO_2 D_2 stage	H_2O_2 P stage	Brightness (%)
Wood waste	DEPD	120	90	2.73	2.00	1.36	1.8	85.9
	XDEDP	180	70	2.18	2.45	1.64	1.8	85.3
	X/2DEDP	180	70	2.73	2.09	1.36	1.8	85.7
Aspen	DEPD	120	90	1.32	2.0-	0.66	1.8	87.7
	X/2DEDP	180	70	1.32	1.17	0.66	1.8	88.4
Loblolly pine	X/2DEDP	180	70	2.96	2.36	1.48	1.8	82.4

[a]Pulp consistency = 10%.
[b]X = xylanase stage; X/2 = half the xylanase used in X stage.

RESULTS AND DISCUSSION

Pulping conditions were similar for all pulps except loblolly pine, where cooking time was 75 min (Table I). Pulp yield of industrial wood waste was about 44.5%, nearly 1% higher than that of loblolly pine (Table I). However, kappa number of the wood waste (24.2) was about 6 points lower than that of loblolly pine (30.7). Thus, the industrial wood waste showed an advantage in pulp yield as well as consumption of bleaching chemicals compared to loblolly pine, which is widely used in the paper industry. Aspen pulp had a yield of 51% and kappa number 17, typical for this species because of its low lignin content. The Douglas-fir used in our experiments was small-diameter trees from thinning of overstocked matured stands. Douglas-fir pulp yield was 48.5%, relatively higher than that of either industrial wood waste or loblolly pine pulp. Moreover, kappa number was only 23.2, close to that of industrial wood waste pulp and considerably lower than that of loblolly pine pulp. The initial brightness of kraft pulp prepared from industrial wood waste, loblolly pine, and Douglas- fir was in the range of 18% to 21% ISO. Aspen pulp showed initial brightness of about 34% ISO.

All pulps were refined in a PFI refiner to various CSF levels in the range of 300 to 600 mL. Figure 1 shows burst index values of all four pulps at various CSF levels. Burst index decreased as CSF level increased, as expected. Industrial wood waste and loblolly pine pulps showed similar burst values at all CSF levels. At similar CSF levels, Douglas-fir showed the highest burst index values, and aspen, a typical hardwood species, showed the lowest values. Figure 2 shows tensile index values of different pulps at various CSF levels. Tensile and burst indices, which are adhesion-based properties, decreased with increasing CSF levels. Fiber properties such as bonding, flexibility, and cohesion improve with refining. Both burst index and tensile index also partially depend on fiber length.

Tear values of industrial wood waste, loblolly pine, Douglas-fir, and aspen pulps remained the same or increased slightly with refining (Fig. 3). Douglas-fir showed the highest tear values, followed by loblolly pine and industrial wood waste. Aspen showed the lowest tear values at all CSF levels. Figure 4 shows the relationship between tear values and tensile index of various pulps. For a similar tensile index, tear values of industrial wood waste pulp were slightly lower than those of loblolly pine; Douglas-fir had the highest tear values. As expected, aspen pulp tear values were low compared to those of softwood and industrial wood waste pulps.

Handsheet density, which is related to fiber flexibility and surface bonding area, is an important property that characterizes pulp quality. Normally, pulp with higher flexibility and/or surface-bonding areas shows higher handsheet density. A close linear correlation between tensile strength or burst index and density should be observed for chemical pulps from both hardwood and softwood. Figures 5 to 7 show the relationship between handsheet density and various strength properties.

In all cases, tensile index increased with handsheet density (Fig. 5). For similar handsheet density, tensile index of industrial wood waste pulp was substantially higher than that of loblolly pine pulp, but slightly lower than that of Douglas-fir pulp; tensile index of aspen pulp was at least 20% lower than that of industrial wood waste. Similar to tensile index, burst index of pulps also increased with handsheet density (Fig. 6). Both loblolly pine and industrial wood waste followed the same density-burst index relationship. For similar density, Douglas-fir showed the highest burst index and aspen the lowest. Unlike tensile index and burst index, tear index remained unaffected by increase in handsheet density (Fig. 7). In fact, tear index depends mostly on fiber length, and tensile index and burst depend on relative bonding areas of handsheet surfaces.

Light scattering coefficient can be indirectly related to other pulp properties, such as tensile index and burst index through fiber surface properties. For a pulp of the same quality, increasing interfiber bonding increases tensile index and burst index, but reduces fiber surface area available for light scattering. Burst index and scattering coefficient correlated very well for industrial wood waste, Douglas-fir, and aspen pulps. Loblolly pine pulp showed low scattering coefficient compared to that of industrial wood waste pulp for a similar burst index (Fig. 8). As shown in Figure 9, scattering coefficient for industrial wood waste pulp was higher than that of loblolly pine pulp for similar tensile index. Indeed, both burst index and tensile index are properties based on surface bonding and they are inversely related to scattering coefficient. As shown in Figures 8 and 9, pulp scattering coefficient decreased with an increase in burst and tensile index values. Scattering coefficient of loblolly pine pulp remained unchanged with variation of tensile index or burst index values. This result is quite different from that for aspen, wood waste, and Douglas-fir pulps. High scattering coefficient and high burst values are unique beneficial properties of industrial wood waste pulp.

The results of our work indicate that the industrial wood waste was a mixture of various hardwood and softwood species. Mechanical properties. like burst, tensile, and tear indices, of the industrial wood waste pulp were closer to that of softwood pulp rather than hardwood pulp. Handsheet density and light scattering coefficient of industrial wood waste pulp also indicate the presence of hardwood species, probably in small quantity. Since the industrial wood waste was collected from California where softwoods predominate, the collected materials might have contained around 85% softwood. This unique blend of hardwood and softwood in the industrial wood waste gave a unique kraft pulp, which was similar to or better than the loblolly pine kraft pulp.

There is no doubt that aspen pulp was more effectively bleached than was the softwood pulp and consumed less chlorine dioxide (Table II). It is surprising that industrial wood waste pulp was far more effectively bleached than loblolly pine pulp and consumed less chlorine dioxide under similar bleaching conditions. Brightness of industrial wood waste pulp was 85.7% ISO compared to 82.4% ISO for loblolly pine pulp. Because of its low kappa number, industrial wood waste pulp required substantially less bleaching chemicals to reach the target brightness level. The low kappa number and easy bleaching character of industrial wood waste pulp are an additional indication of the presence of hardwood in the wood waste mixture. It is also possible that aging and natural weather conditioning of the industrial wood waste helped release part of the unwanted extractives and was partly responsible for the superior bleaching response.

CONCLUSION

The kraft pulping process is very suitable for industrial wood waste, which is a mixture of hardwood and softwood. Pulp yield is similar to softwood pulp yield and kappa number is relatively low. Mechanical properties of industrial wood waste pulp are similar to those of softwood pulp and far better than those of hardwood pulp. The response of industrial wood waste pulp to conventional elemental chlorine-free bleaching chemicals was better than that of loblolly pine pulp. We will continue further work on industrial wood waste collected in other regions of the United States.

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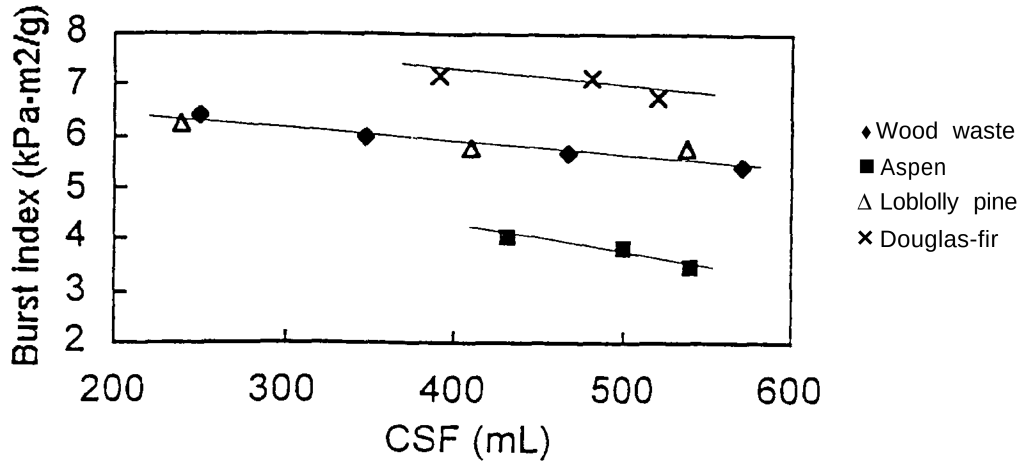

Figure 1 Relationship of burst index to CSF.

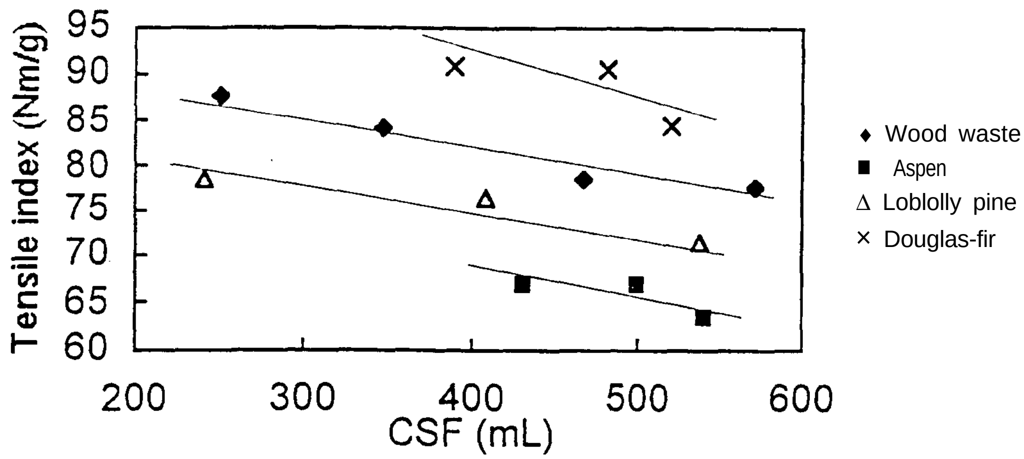

Figure 2 Relationship of tensile index to CSF.

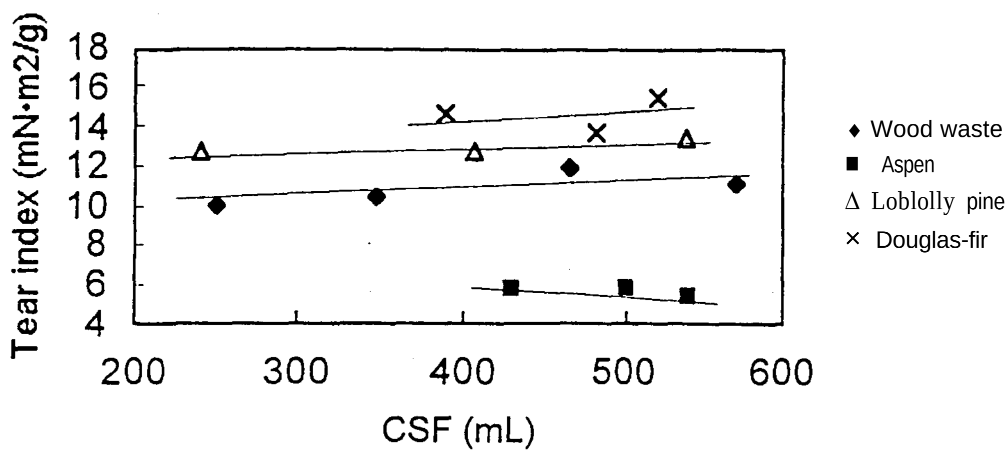

Figure 3 Relationship of tear index to CSF.

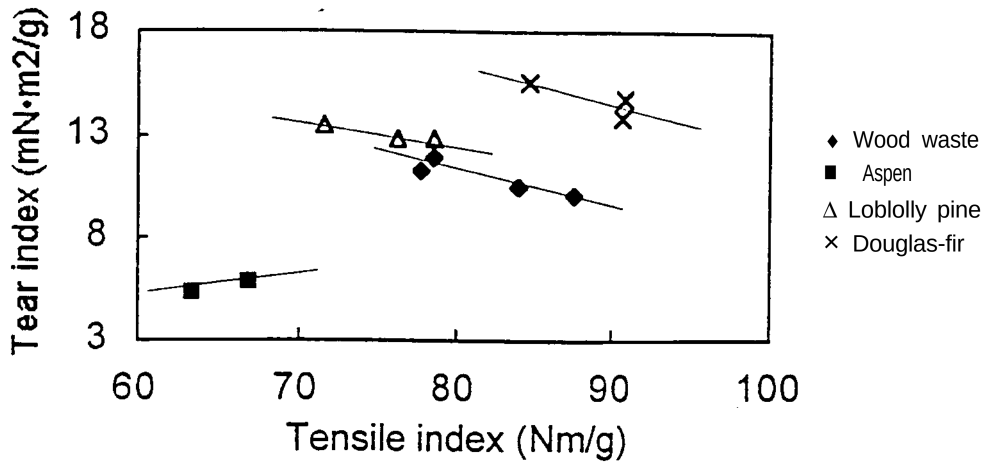

Figure 4 Tear index vs tensile index.

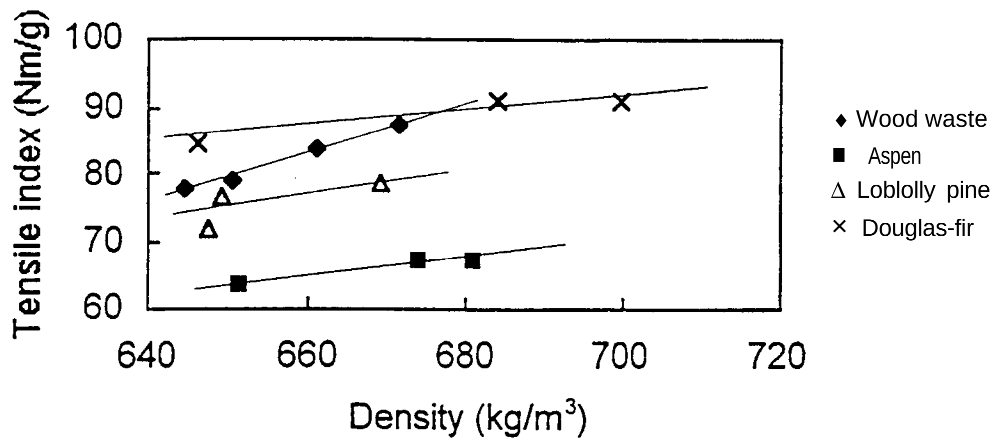

Figure 5 Relationship of density to tensile index.

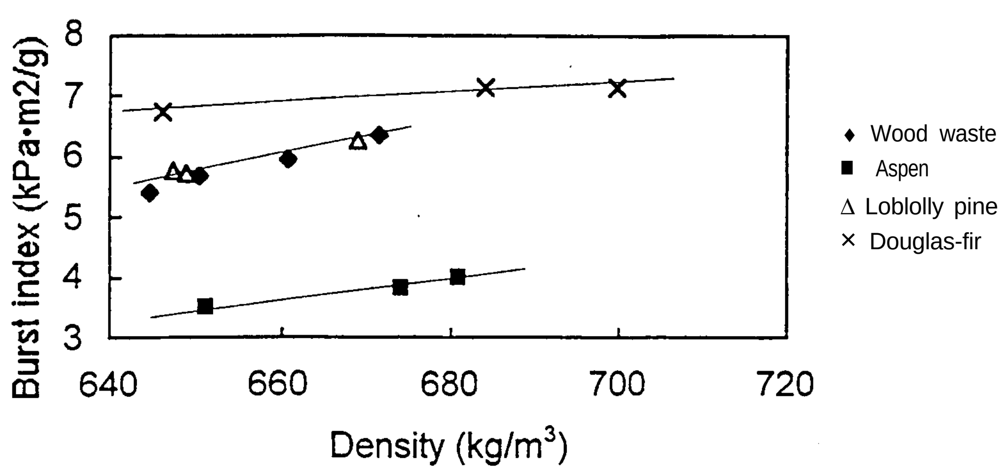

Figure 6 Relationship of density to burst index.

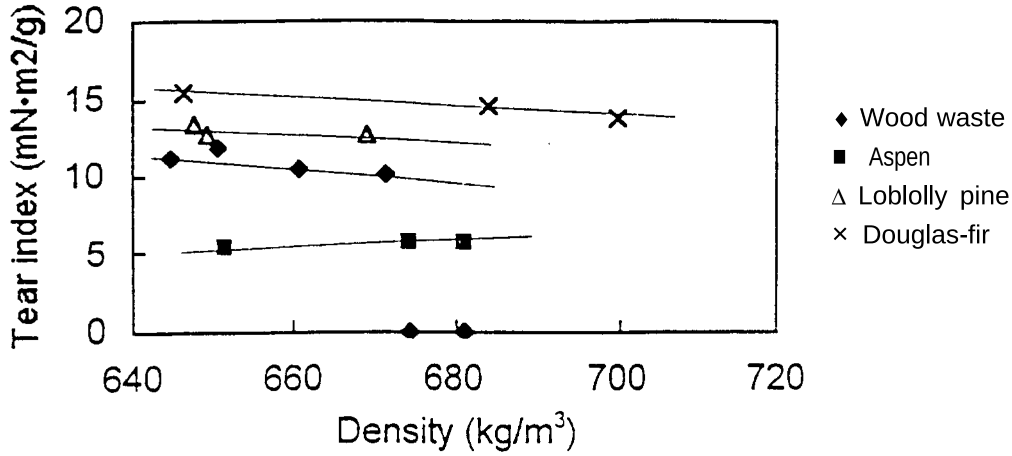

Figure 7 Density vs tear index.

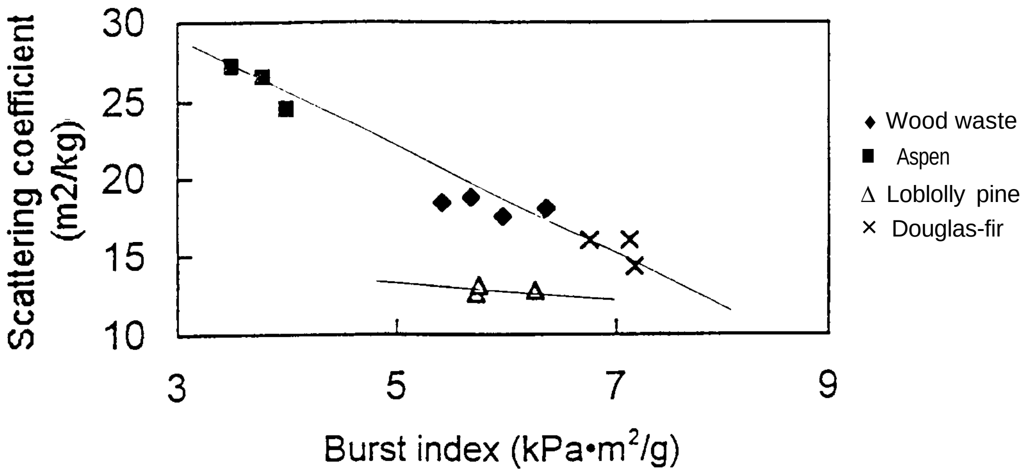

Figure 8 Burst index vs scattering coefficient.

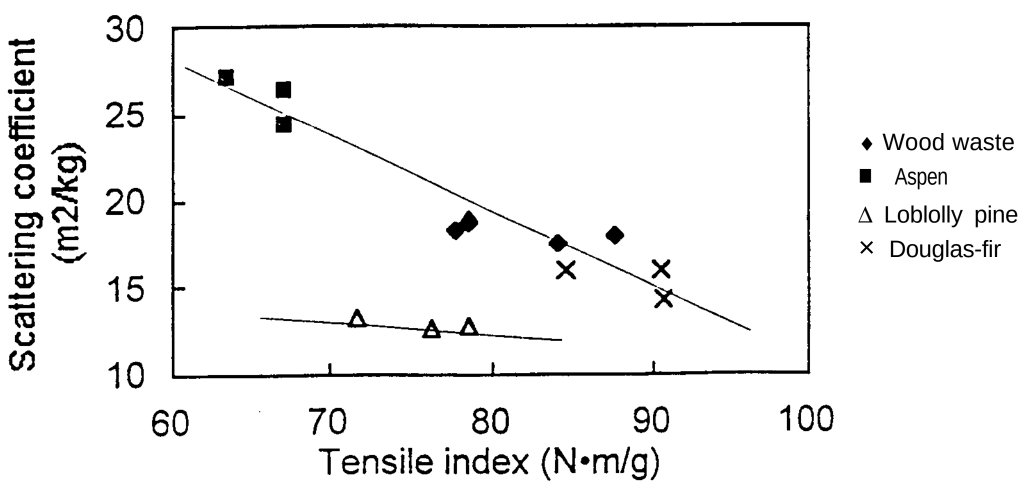

Figure 9 Tensile index vs scattering coefficient.