The Use of Acoustic Emission to Detect Fines for Wood Based Composites, Part Two: Use on Flakes

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Oriented strand board (OSB) is commonly used for structural applications. Manufacturers of OSB want to minimize the presence of small particles or "fines" in the panels because fines increase the consumption of resins, leading to an increase in the weight of the board. Fines are produced when either a refiner or chipper blade becomes dull, or when the wood raw material becomes excessively dry. By accurately monitoring the presence of fines, manufacturers can help control their percentage within a product. Acoustic emission (AE) is an elastic or plastic wave generated when a surface is deformed or has an external force exerted on it. This research shows the feasibility of using AE to monitor the presence and percentage of fines in flakes. The study follows up on previous research conducted years ago by Lemaster (1994). The study also shows the effect of the flake geometry and flake moisture on the AE signal.

Keywords: Flakes; Fines; Acoustic emission; Process monitoring

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INTRODUCTION

As the use of wood-based composites continues to grow, oriented strand board (OSB) competes with plywood for strength applications such as roof sheathing. Newer products, such as orientated strand lumber and laminated veneer lumber, are also beginning to compete with traditional lumber in strength critical applications. These composites allow for the use of smaller diameter trees as well as material that in the past would have been considered residual or by-products. Wood-based composites continue to improve in performance and are known to use environmentally friendly or sustainable adhesives. Additionally, improvements have also been made in how panel products are made. Continuous pressing techniques and improved process monitoring/control sensors have resulted in better panel product consistency. The size and shape of the fibers, particles, or flakes in a composite are extremely important in the properties and performance of the final panel product (Maloney 1993). Other factors affecting the properties and performance of a panel product include wood species, type and amount of binders, and other additives. Parameters such as board structure, as determined by mat forming, layering, and the pressing conditions, also affects the board properties. As Maloney states, however, "particle geometry interacts intimately with virtually all of these parameters in determining board properties" (1993). The reader is referred to Part One of this study for a more complete discussion on the generation and effects of fines in wood-based composites (Campbell *et al.* 2018)

The need to classify and separate particles is not unique to the wood industry. One technique that has shown promise in monitoring the size of particles in the power industry is monitoring acoustic emission (Leach *et al.* 1977). Acoustic emission (AE) is defined as the elastic energy that is spontaneously released when a material undergoes deformation (Miller and McIntire 1987). Acoustic emission is low intensity, high frequency (100 kHz to 1 MHz) elastic waves that propagate in all directions through a structure. When these elastic waves strike an AE sensor, which contains piezoelectric material, the mechanical energy is converted to electrical energy that can then be amplified, filtered, and processed. The decaying signal can then be quantified by a number of waveform descriptors such as the signal energy, peak amplitude, and signal duration (Fig. 1).

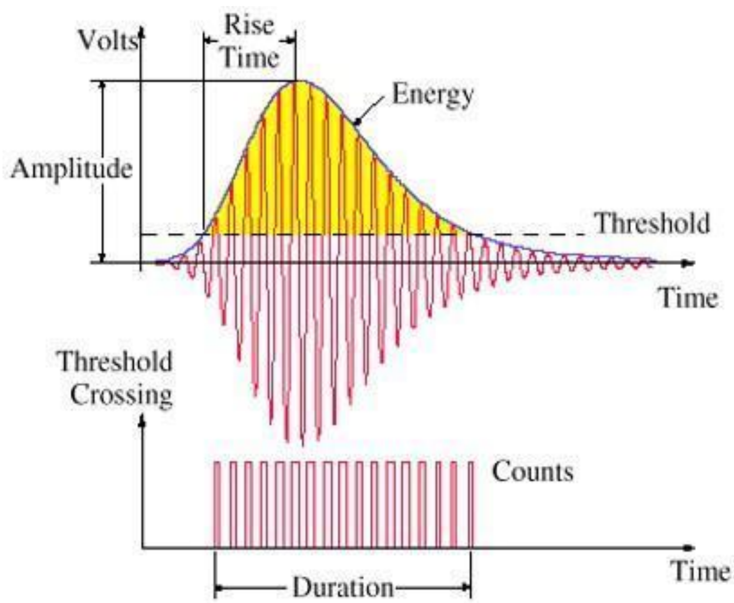

Fig. 1. Example of acoustic emission signal with common waveform descriptors (Ramasso *et al*. 2012)

This study is a refinement of a study conducted previously by Lemaster (1994). That preliminary study was never followed up due to a change in jobs and research focus by Lemaster as well as a machine vision system that was introduced at that time that showed promise for the composite industry. Recent consultation with manufacturing personnel revealed that the detection of fines is still and issue and that the machine vision technique was never really accepted. In the original study, AE was used to classify both wood particles and flakes. The study showed that a larger number of sample waveforms would result in less variability in the resulting data. In that study, a small sample of wood material was dropped onto a target with the AE sensor attached. The sample was dropped either by placing it on a trap door and dropping it all at once, or by sliding the material down a small slide onto a target. The current study used a target placed inside a cement mixer filled with the wood particles or flakes. The mixer rotated, allowing the material to fall onto the sensor and then slide off. This simulated flakes or particles coming down a conveyor or pipe. This allowed for a high number of samples, which reduced the variation in the technique. The study was conducted in two parts. The first part attempted to optimize the experimental procedure by determining the best sensor frequency to use as well as the best AE signal descriptor to use. The previous study used particleboard furnish. The second part of the study, reported here, evaluated the technique's ability to characterize the size of flakes and detect the percent of fines in the mix. A quick experiment was also conducted to determine the effect of chip moisture content on the AE signal.

EXPERIMENTAL

The objective of this study was to determine the feasibility of using AE for monitoring the percent fines in a mix of wood flakes. Furthermore, the objective included determining effect of flake size and the moisture content of the flakes. The series of tests included:

1. The effect of width and length of paper simulated “flakes” on AE signal level.
2. The effect of the size mixture of paper flakes on AE signal level.
3. The effect of fines in a mixture of paper flakes on AE signal level.
4. The effect of the percent fines in paper flakes on AE signal level.
5. The effect of paper flakes’ moisture on AE signal level.
6. The effect of fines within a size mixture of wood flakes on AE signal level.
7. The effect of the size mixture of wood flakes on AE signal level.

Materials

The same cement mixer was used in both Part I and Part II of the associated studies. The mixer, however, had to be modified to successfully tumble flakes. Preliminary studies showed that the flakes would not tumble correctly when both shelves were installed, because the flakes would bunch together and bridge between the two fins. When one shelf was removed, the flakes correctly tumbled onto the target. Each individual chip or flake does not need to fall onto the target individually, but the material needs to freely fall onto the target and not partially get caught on the sides of the tumbler or between the fins. The support arm for the sensor also had to be reinforced as the number of flakes that were tumbled had a combined weight that was heavier than the particles tumbled in Part I and caused the original support arm to vibrate excessively. Each experiment was also run for two minutes instead of the one-minute limit used in Part 1. This change made the number of material drops between the two studies consistent (one drop per revolution instead of two drops per revolution in Part 1).

The first set of experiments in this study used simulated wood veneer flakes. This was an attempt to reduce the variability in the study when evaluating the size of the flakes. Four different sizes of flakes were cut from veneer that had an average thickness of 0.050 inches (1.27 mm). The average flake thickness obtained from a nearby OSB plant was 0.029 inches (0.74 mm). When the thicker veneers were tumbled, they hit the sensor as a group and slid off and did not appear to tumble the same way as typical wood flakes did. Therefore, 140 lb. paper was substituted for the veneer wood simulated flakes. The average thickness of the paper was similar to that of the real flakes (with a thickness of 0.030 inches) and seemed to tumble similarly to the wood flakes. Simulated flakes were cut into the following widths and lengths (in inches): 2 x 6, 1 x 6, 2 x 3, 1 x 3, .5 x 3, .5 x 1.5, .25 x 1.5, .5 x .75, and .125 x .5 (fines); or in millimeters: 50.8 x 152.4, 25.4 x 152.4, 50.8 x 76.2, 25.4 x 76.2, 12.7 x 76.2, and 12.7 x 38.1 (fines), respectively. These simulated flakes were tumbled separately to determine if the AE signal changed when different sizes of paper flakes were tumbled. Next, a mix of several sizes of the paper flakes were tumbled, and the AE signal measured, to see if the AE system was sensitive to a mix of different sized flakes. In another series of tests, the paper flakes were mixed with simulated fines to see if the system was sensitive to fines. Lastly, 2 x 6 inch paper flakes were placed in conditioning chambers to reach equilibrium moisture contents (EMC) of 2.5, 5.7, and 20.4%, respectively. These flakes were then tumbled separately to determine the effect of flake moisture content on AE signal levels.

Actual OSB wood flakes were obtained from NorBord in Kinards, SC, USA. Three different size groups (small, medium, and large) of flakes were manually sorted. The approximate sizes of the groups were small (2.5 inches long, 63.5 mm), medium (4.0 inches, 101.6 mm), and large (6.5 inches, 165 mm). The width of the groups ranged from 0.125 to 1 inch for the small flakes (3.175 to 25.4 mm) to 1 to 3 inches (25.4 to 76.2 mm). Fines were simulated by generating small strands on a CNC router by machining white pine with a single flute cutter at a spindle speed of 12,000 rpm and a feed speed of 350 inch per minute (8.89 meters per minute). This resulted in a tooth advancement of 0.029 inch per revolution (0.741 mm per revolution). When machining 0.75 inch (19.0 mm) thick pine, the machining condition resulted in fine strands with a tapered thickness that averaged 0.029 inch. Figure 2 shows the three sizes of wood flakes.

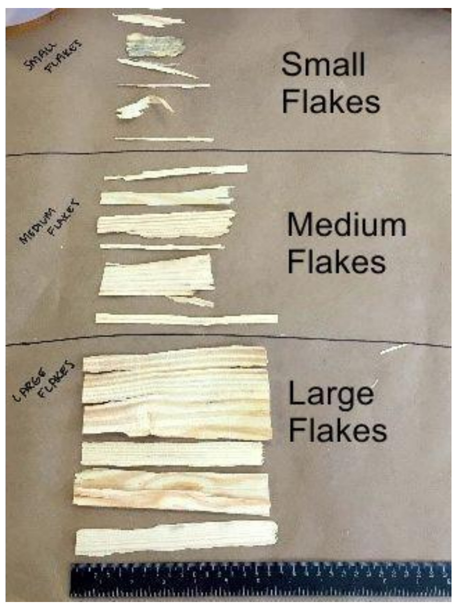

Fig. 2. Three size categories of wood flakes (largest flakes approximately 6.5 inches, 165 mm long)

Flakes were weighed before testing to assure the same amount of flakes were used regardless of size. Fines were considered material that would pass through a 50-mesh screen (*i.e*., 50 openings per inch; the opening is 300 microns).

Methods

The acoustic emission setup was a Mistras USB AE Node (Princeton Junction, NJ, USA). This USB based unit allows for collection of the AE signal up to 10 Msamples/sec, as well as the extraction and recording of waveform feature descriptors. The software used for data acquisition, feature extraction, and recording was AEwin™ by Mistras (Princeton Junction, NJ, USA). The AE unit uses piezoelectric sensors with integral preamplifiers. Based on results from Part One, the sensor used was a 150-kHz resonant sensor with a gain of 52 dB. The AE descriptor that showed the most sensitivity to changes in the particle sizes in Part One was the energy of the signal.

The sampling speed was set at 1 Msamples/sec for a waveform length of 1000 samples. This meant that 1 waveform was being collected every 1 microsecond. Each test consisted of tumbling the particle mix for 120 seconds. This resulted in 100 revolutions of the tumbler or 100 particle drops. Each drop of flakes, however, resulted in multiple AE waveforms being generated.

Three AE timing parameters could be controlled for AE waveform collection. These included peak definition time (PDT), hit definition time (HDT), and hit lockout time (HLT). In brief, a proper setting of the PDT ensures correct identification of the signal peak for risetime and peak amplitude measurements. Proper setting of the HDT ensures that each AE signal from the structure is reported as only one hit. With proper setting of the HLT, spurious measurements during the signal decay are avoided and data acquisition speed can be increased. Based on the results from Part One, the timing parameters were set at 500, 1000, and 12,000 for PDT, HDT, and HLT, respectively.

RESULTS AND DISCUSSION

Paper Flake Tests (Part One)

The first test consisted of tumbling different sizes of paper flakes and measuring the AE signal energy for each size category. Four replications for each flake size were conducted. For smaller flake sizes, the average energy levels were lower. Figure 3 is a chart of average signal energy per size as a percent of energy from the 2 x 6 flakes, the largest size exhibiting the highest energy.

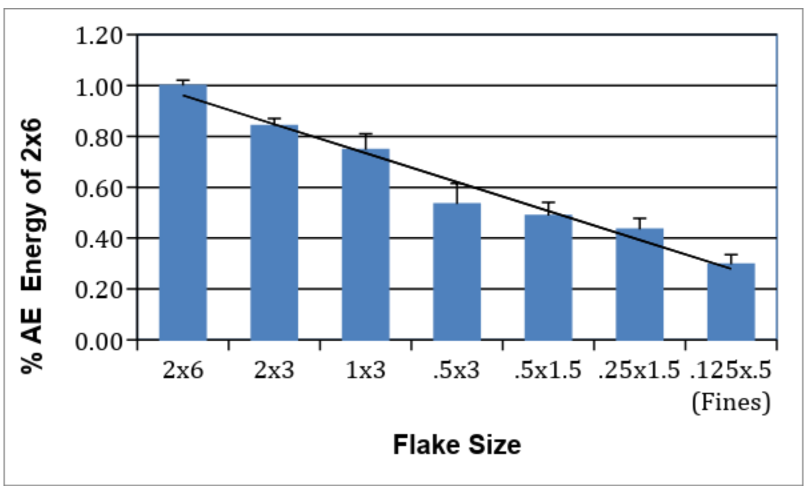

Fig. 3. Effect of paper flake size on AE signal energy (error bars = coefficient of variation, standard deviation / mean)

The only size not included in the figure is the 1 x 6 flake data, as the 1 x 6 flakes did not tumble well. Due to the flakes being long and slender, they tended to become tangled together and fall on the AE target as a "lump" instead of individual flakes. The other flake samples all tumbled well. The failure of the 1 x 6 to tumble successfully is not anticipated to be a problem, because in a manufacturing plant, the distance and angle of the flakes falling onto the AE target can be controlled. In the laboratory, when the flakes were dropped from a higher distance, they tended to separate better than when in the tumbler. The falling distance in the tumbler, however, could not be increased. Because the weight of the paper flakes was lighter than the actual wood flakes, it was decided to “normalize” the AE signal energy levels to the signal energy of the largest flake, 3 x 6 inch. This approach means that any threshold to indicate an unacceptable level could be set using the largest flake expected. This would make it easy to calibrate the AE system when changing flake geometry or species. A linear regression was conducted on the paper flakes and yielded an R^2 of 0.969 (Fig. 3).

Even though the controlled size tests provided linear results, not all flakes are identical in the manufacturing of OSB. In order to ensure that a mix of different sizes would still show energy differences with a decrease in overall sizes, three different mixes were used: The first mix was composed of half 2 x 6s and half 2 x 3s, which would be ideal because those sizes simulate less “wear and tear” on the flaker blades. The second mix consisted of 2 x 6s, 2 x 3s and 1 x 3s in equal parts, and the last mix was composed equally of 2 x 3s and 1 x 3s. Figure 4 shows that there were noticeable differences among the three groups. It was speculated that the group with three flake sizes had a higher standard deviation as there was more variability in the flake sizes in that mix. In a real world situation it is expected that the variation between flake sizes to be much more varied than this thee categories of paper flakes. This was just to illustrate the sensitivity of the AE technique to different sizes of flakes. In the section below using actual wood flakes the categories were indeed much more varied.

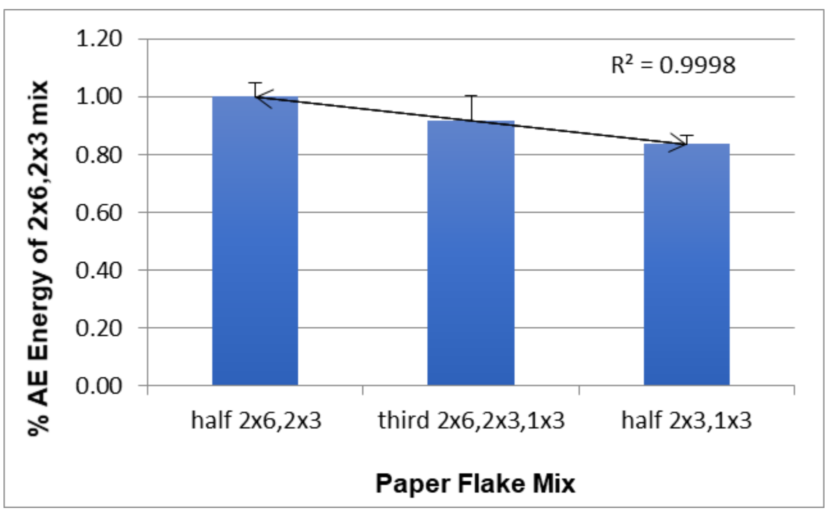

Fig. 4. Effect of paper flake size mix on the AE signal energy (error bars = coefficient of variation, standard deviation / mean)

To simulate a real-world condition, a much more varied mix of the simulated flakes was used for another test. In this test the mix was composed of 2 x 6, 2 x 3, 1 x 3, and 0.5 x 1.5 (25% each) flakes. Four replications of that mix with no fines were conducted, followed by four replications with 10% fines added (evenly among sizes while removing 10% of the flakes by weight). The replications were run to compare energy levels. Fines for the paper flake experiments were defined as the smallest flakes prepared and were 0.125 x 0.50 inches (3.175 x 12.70 millimeters). Figure 5 shows a plot of a mix of paper flakes that contained 25% each of 2 x 6, 2 x 3, 1 x 3 and 0.5 x 1.5 inch flakes with 0 and 10%

fines. The average energy of the mix without fines was 10.59 and the mix with 10% fines was 9.71. This showed a decrease of approximately 8.4%, which should be significant enough to be detected in an on-line system.

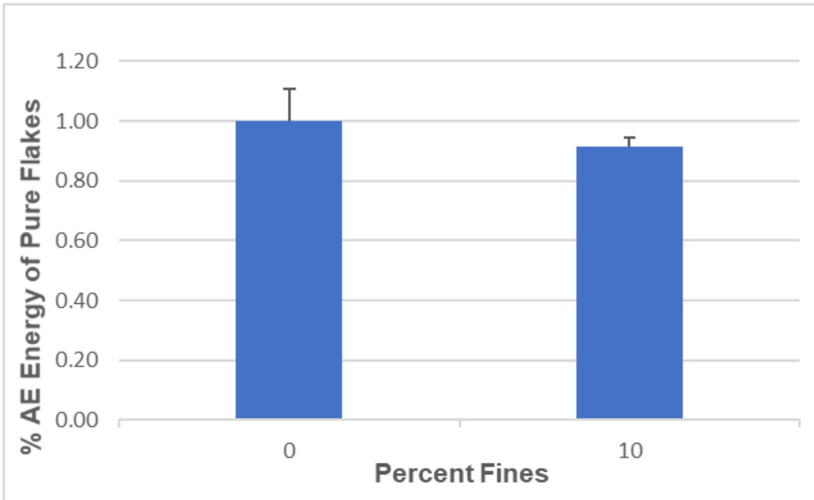

Fig. 5. Effect of the presence of fines on paper flake size mix of 25% each of 2 x 6, 2 x 3, 1 x 3, and 0.5 x 1.5 inch flakes on the AE signal energy (error bars = coefficient of variation, standard deviation / mean).

Another experiment consisted of using the 2 x 6 inch paper flakes and then progressively adding more paper flake fines. Again, four replications for each condition were tested. Figure 6 shows the results of the AE signal level with 0, 5, 10, and 15% fines. The AE technique detected differences in the percent fines at all fines levels. A linear regression showed an R^2 of 0.977.

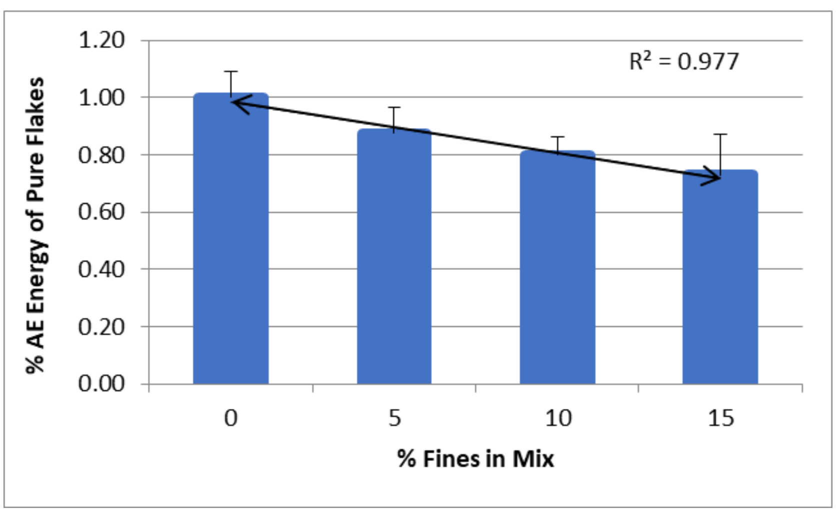

Fig. 6. Effect of the presence of different percent of fines on 2 x 6 inch paper flakes on the AE signal energy (error bars = coefficient of variation, standard deviation / mean)

A final test with the paper simulated flakes attempted to determine the effect of moisture content on AE. As wood becomes dryer, more fines are generated during machining. Moreover, moisture content can fluctuate due to seasons as well as the time between log harvesting and machining into flakes. The large paper flakes (2 x 6 inch, 50.8 x 152.4 mm) were conditioned to an EMC of 2.5, 5.7, and 20.4%, respectively. The flakes were then tested. Figure 7 shows that at the moisture contents tested, and due to the variability of the results, changes in EMC did not have a significant effect on the AE signal level.

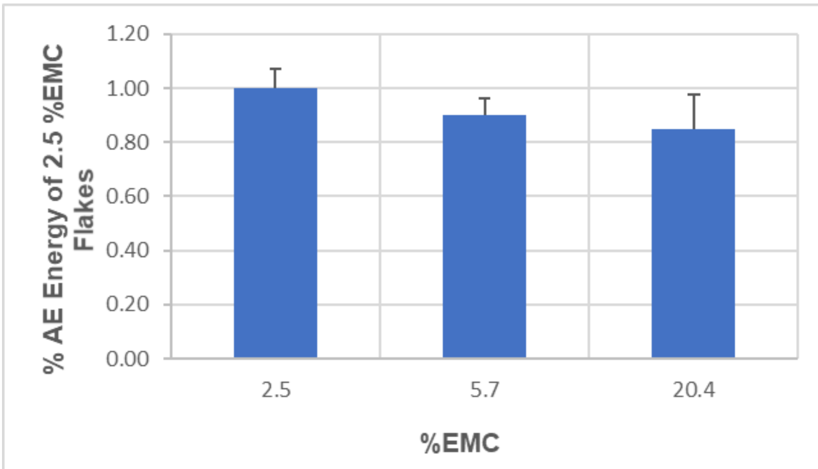

Fig. 7. Effect of changes in Equilibrium Moisture Content of 2 x 6 inch paper flakes on the AE signal energy (error bars = coefficient of variation, standard deviation / mean)

Wood Flake Tests (Part Two)

The initial paper flake experiments showed that the AE system was sensitive to both changes in flake sizes as well as the presence of fines. Therefore, it was important to verify that the system was also sensitive to changes in actual wood flakes. The first experiment consisted of taking the mix of wood flakes and systematically adding more fines to the mix while removing the same amount of flakes by weight and then tumbling the mix while recording the energy levels. The results showed that with an increase of fines, the AE signal energy decreased. Figure 8 displays this trend. A linear regression shows an R^2 value of 0.992.

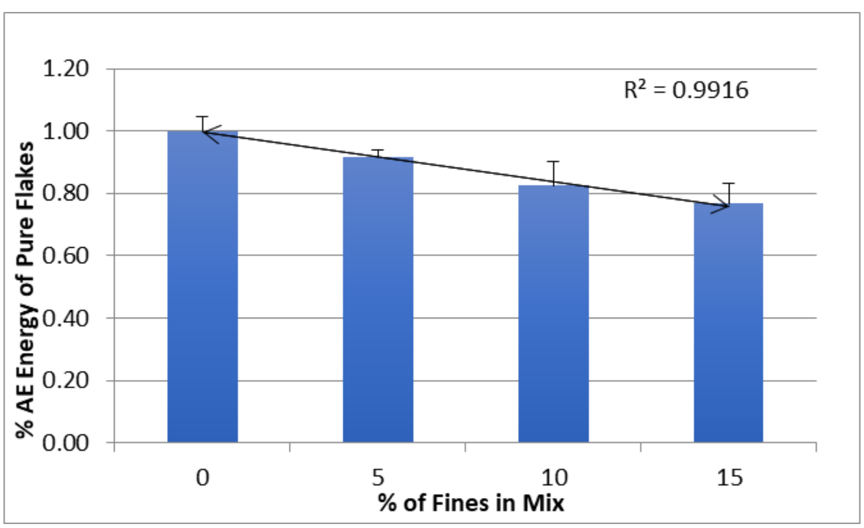

Fig. 8. Effect of different percent of fines in a mix of wood flakes on the AE signal energy (error bars = coefficient of variation, standard deviation / mean)

After testing the overall mix, an experiment was conducted to determine the difference in AE signal energy level between the three size categories of wood flakes. As shown in Fig. 9, the signal level dropped approximately 10% from the large flakes to the medium flakes. From the medium flakes to the small flakes, the signal level dropped by approximately 3.2%. These differences occurred even though the same amount (by weight) of flakes were tested each time. Fewer larger impacts still generated more signal energy than more impacts from smaller flakes.

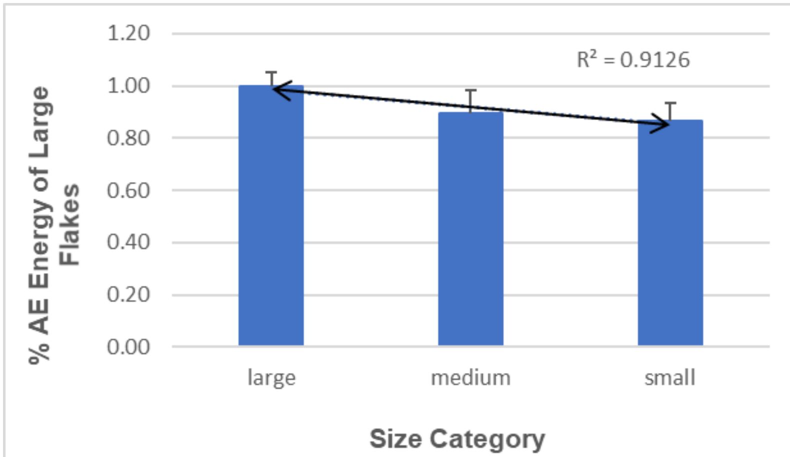

Fig. 9. Effect of the presence of different percent of fines in a mix of wood flakes on the AE signal energy (error bars = coefficient of variation, standard deviation / mean)

Acoustic emission sensing demonstrates good potential as a method to monitor the size of flakes, as well as the presence of fines in the flake mix. This method is able to be placed online in a manufacturing process, such as a conveyor pipe transport, and collect data continuously. The large amount of data collected will provide the manufacturer with continuous information on the state of the flaking operation. As expected, having a calibrated sensor and an appropriate target in a location that all flakes are evaluated is crucial to obtain accurate results**.** A primary advantage to using the acoustic emission sensing method is that it can be essentially self-calibrating. A manufacturer will need to monitor the AE signal levels when the refiner or flaker blades are first changed. Then, by monitoring the quality of the flakes and the resulting percent AE signal change, the manufacturing will establish a criterion of when the refiner blades need to be replaced to maintain a desirable flake quality. Once established, the criterion should work satisfactorily regardless of small changes in raw material density, moisture content, etc. This will change the absolute AE signal levels but should not affect the percent changes of the AE signal level to replace the blades. Additional work will need to be conducted to establish the effect of different raw material species. It is presumed this could be done as field studies at different manufacturing locations or by the manufacturers themselves.

CONCLUSIONS

1. The AE system was able to detect differences in the size of paper simulated flakes.
2. The AE system was able to detect difference in mixtures of 50% and 33% of different size categories of paper simulated flakes.

3. The system could detect when 10% fines were added to a mixture of different sizes of paper flakes.
4. The AE system could detect the differences between 0, 5, 10, and 15% fines when added to a mix of 2 x 6 inch (50.8 x 152.4 mm) paper flakes.
5. Changes in moisture content of paper flakes did not appear to significantly affect the AE signal level at the range of EMC tested.
6. The AE system could detect difference between 0, 5, 10, and 15% fines in a mixture of small, medium, and large wood flakes.
7. When tumbling small, medium, and large wood flakes, the resulting AE signal energy level decreased as the size of the flakes decreased. The larger the difference in the weight of the flakes, the greater the difference in the AE signal level.

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