Development of Delaminate Inspection by Using Sound Sensor and Pattern Recognition Technique

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Abstract. Windsurf manufacturing and inspection process have high influence for product quality. Recently windsurf manufacturer faced high nonconformity cost with delaminate problem. Current inspection process is performed by inspector skill which depends on the experience. The inspection method is proposed by using sound sensor and applying the Fast Fourier Transform to monitor the ranges of laminate and delaminate frequency. The pattern recognition technique is purposed to classify noise frequency in order to identify the laminate windsurf from the delaminate ones. This research investigates the delaminate among the polyvinyl chloride sheet, the biaxial carbon reinforced fabric and the fiber glass reinforced fabric. The area of laminate frequency in frequency domain shows the laminate point has high power spectrum density than the one from the delaminate point. The algorithm to detect the delaminate has been developed and proved by real windsurf. It's proved that the method proposed can be identified the delaminate windsurf.

1. Introduction

Windsurf has been one of Olympic sailing events and starting in Olympic games since 1984 for men and 1992 for women. Nowadays windsurf is one of water sport which famous in Europe and Australia. Windsurf has three kinds of board which have different shape and dimension. There are short board, long board and fun board each type are suitable for different speed and surfing characteristics but the same requirement is "Straightness". Windsurf are used in water with stress from player at step position with long duration during surfing. Hence position which have to bear weight from player and equipment must have more straightness than other area. This requirement induce windsurfs material and its manufacturing process have high priority to be considered. Recently windsurf swelling problem occurs with low using hours. Manufacturer define this problem as "Delaminate". This problem causes player displease and effect to buying decision. Windsurf manufacturer emphasizes and realizes for straightness and customer satisfaction. It is leading to windsurf manufacturing and inspection improvement.

Material properties in windsurf structure are emphasized. Windsurf is contained polyvinyl chloride, fiber glass reinforced fabric and biaxial carbon reinforced fabric. Windsurfs core is made by expanded polystyrene density 0.0155 g/cm^3. Each material is laminated with epoxy resin manually then send to vacuum processing. Laminate process is difficult to control process stability. Inspection process is established in order to detect delaminate between composite material before dispatch to customer. Mostly

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delaminate point occur between polyvinyl chloride sheet and fiber glass reinforced fabric. Both component is separated apparently and reduce product life time. Current inspection process is “knocking and listening sound” by inspector as shown in figure 1.

Figure 1. Inspection process by knocking.

Many researches show the results of sound detection in abnormal equipment which can be achieved by different power spectrum identification. Electric motor timely maintenance uses the vibration signal and acoustic sound signal for fault diagnosis. The component contained two broken rotor bar, mechanical unbalanced and bearing fault. The power spectrum in frequency domain from CEEMD of acoustic sound signal and vibration signal is different from healthy motor [1].The other research investigate method for rock type characterization by acoustic sound signal and Fast Fourier Transform. Total five rock type were collected from various source and drilling in CNC machine with different condition. Sound from drilling process were utilized to classify type of rock by frequency spectrum in frequency domain. Frequency from drilling process were plot with UCS, BTS and density by regression analysis then compare result of UCS, BTS and density from direct measurement with prediction value. Both value are corresponding with acceptable degree of accuracy [2].Acoustic sound sensor was aim to use in CNC machining field in order to monitor tooling deterioration by combining with 3-component dynamometer, acoustic emission sensor and accelerometer and apply Fast Fourier Transform to obtain sound signal, cutting forced signal, acoustic emission signal and acceleration signal in term of frequency domain. These variable are used for input neutral network with back-propagation to predict tooling deterioration [3]-[4].There are another research in medical field which concern to lung sound analysis. Heart sound signal interfered with lung sound and make confusion for analysis. This research purpose to reduce heart sound interference by empirical mode decomposition technique with algorithm. First IMF obtain heart sound. Then utilize inverse Fast Fourier Transform to obtain lung sound [5]. Ceramic manufacturing also apply Fast Fourier Transform and continuous wavelet transform for in-process tooling failure detection. Propose of this research is to prevent work piece surface deterioration by develop detection method of damaged ceramic tool. Ceramic tool is damaged by chipping during turning from work piece. Camera was used to capture surface and transfer to gray scale. The result found Fast Fourier Transform and continuous wavelet transform can detect onset of chipping in the cutting tool [6].

These researches are evident that sound sensor can be utilized to classify material characteristic, tooling deterioration and abnormal equipment in electric motor by applying Fast Fourier Transform. Frequency domain of different material have differentiate because of its sound frequency. Delaminate inspection is judgement by inspector skill with sound level. They found sound from laminate and delaminate have

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different sound level due to its fullness. Delaminate has low sound level because of low frequency and laminate has high sound level because of high frequency. The differentiate of sound characteristics from laminate and delaminate can be classify by Fast Fourier Transform [7]-[8]. Power spectrum density which indicate material completeness can be utilized to identify laminate level [9]. The laminate level is complicate to indicate so pattern recognition [10] is introduced to establish the optimal value.

2. Experimental equipment and condition

This experiment is performed by choosing the model of windsurf with different type of component. Polyvinyl chloride thickness 3 mm. density 100 kg./m^3 and thickness 3 mm. density 80 kg./m^3 were selected to performed experiment with fiber glass reinforced fabric density 0.06 g./cm^3 and 0.1 g./cm^3 and biaxial carbon reinforced fabric density 0.15 g./cm^3. Windsurf type with different component are shown in table 1.

Table 1. Windsurf type are categorized by component.

Windsurf type	PVC		Fiber glass reinforced fabric (g./cm^3)	Biaxial carbon reinforced fabric (g./cm^3)
	Thickness (mm.)	Density (kg./m^3)		
Windsurf 1	3	100	0.1	-
Windsurf 2	3	100	0.06	-
Windsurf 3	3	80	0.06	-
Windsurf 4	3	80	0.06	0.15

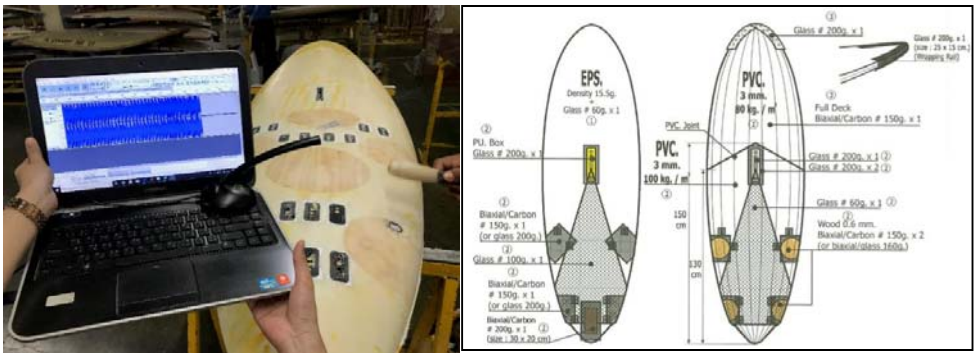
2.1 Sound acquisition

Sound acquisition is performed by microphone USB Digital Noise Cancelling Speech Mic and sound recording program (Audacity). Inspector knocking on windsurf by special knocking equipment. This equipment is made by resin with shape and weight controlled (130-140 g.). Then sound recording is started and saved as ".wav". Inspection station is located nearby pressing area. There are sound from mold knocking and other environment sound which can disturb inspection process. Noise from these process need to be identified by sound recording and using Fast Fourier Transform to obtain frequency in frequency domain.

2.2 Experiment performing

This experiment is performed by inspector skill. Laminate and delaminate point were collected by inspector judgement as shown in figure 2. First step inspector knocking to check laminate. When they found delaminate point then sound recording is started with knocking duration 10 second. After that recording sound from laminate point with the same duration. When sound recording is finished both laminate and delaminate point were proved judgement result by surface cutting to see bonding. Actually windsurf is coming for inspection continuously but monitoring is proceeded until sound recording complete 30 point for laminate and delaminate per windsurf type. Cutting surface were took a photo for reference.

Knocking sound from each type of bonding (laminate, delaminate and partial laminate) will be transferred to frequency domain by Fast Fourier Transform. Frequency domain of laminate point show apparent one frequency. This frequency is recorded as “laminate frequency” and frequency domain of delaminate point show different frequency which define to “delaminate frequency”. Area at laminate frequency for both laminate and delaminate point will be integrated and plot with windsurf no. in order to investigate trend or differentiate between each type of bonding. After that area differentiation is utilized to establish delaminate criteria by pattern recognition algorithm as shown in figure 3.



(a) (b)

Figure 2. Experiment set up (a) and windsurf layup (b) (Expanded polystyrene, Polyvinyl chloride, Fiber glass reinforce fabric, biaxial carbon reinforced fabric).

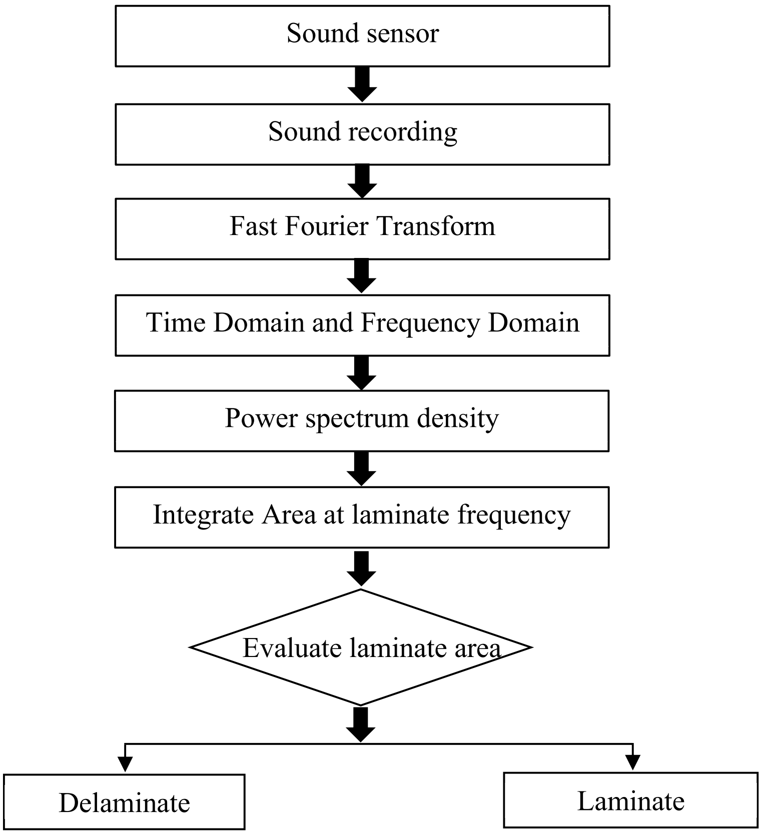


Figure 3. Experiment algorithm.

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2.3 Laminate area acquisition

After obtain laminate frequency from each windsurf type. As laminate frequency of windsurf 2 shows the maximum frequency [11] of the laminate windsurf at 285.4 Hz as shown in figure 4. Laminate is starting at frequency 260.4 to 310.4 Hz. So the laminate frequency range is defined as ±25 Hz. It will be used to calculate the laminate area for other laminate frequency of all windsurf type.

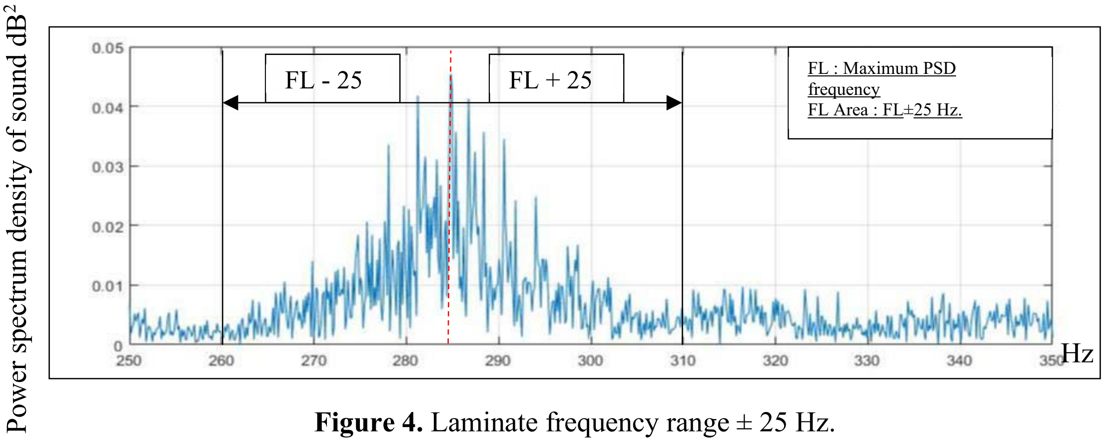
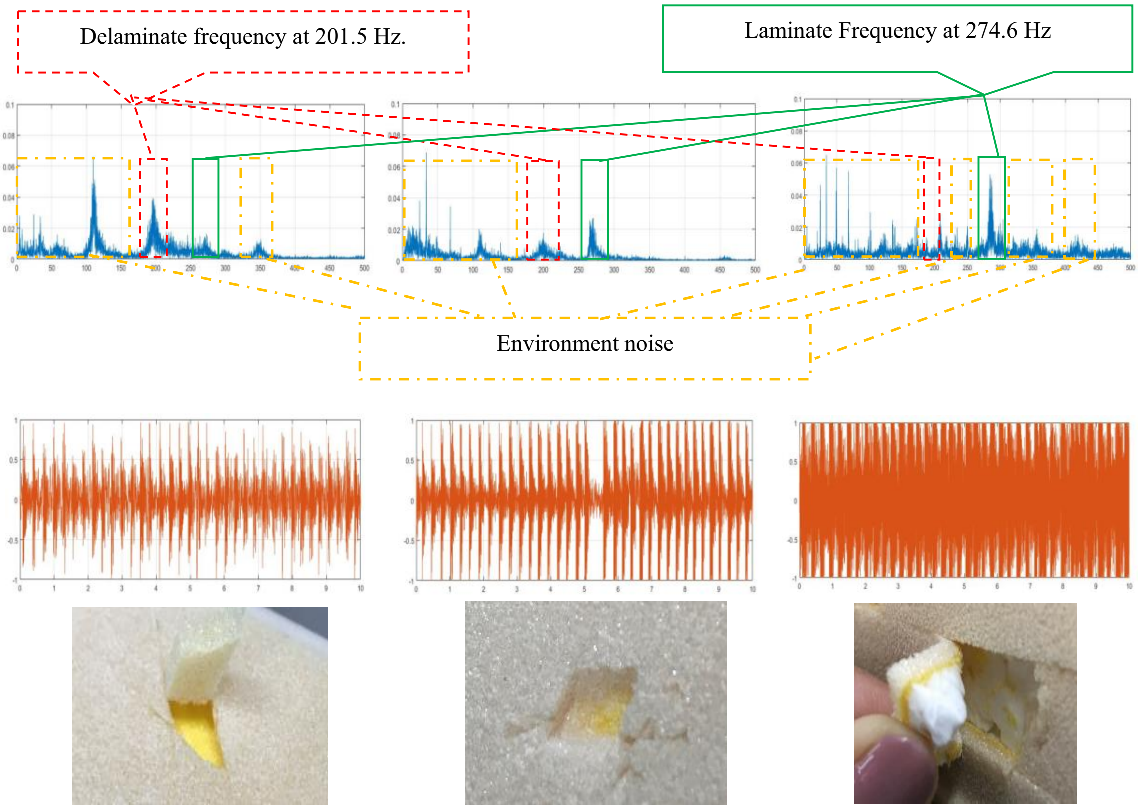


Figure 4. Laminate frequency range ± 25 Hz.

3. Results and discussions

Physical judgement by surface cutting, time domain and frequency domain of laminate, delaminate and partial delaminate point of windsurf 3 are shown in figure 5. Laminate point is difficult for cutting and polyvinyl chloride sheet is not peel off from glass fiber reinforced fabric. Expanded polystyrene still attach on polyvinyl chloride surface. Delaminate point is easy for cutting and polyvinyl chloride sheet is separated from fiber glass reinforced fabric easily and no resin remain on polyvinyl chloride sheet. Partial delaminate point has different characteristic from laminate and delaminate point. No resin on polyvinyl chloride sheet and it can be removed from fiber glass reinforced fabric but no gap between both materials .It is not separated from fiber glass reinforced fabric completely.

Consider frequency domain which show noise from environment,laminate and delaminate frequency. Frequency domain interpret laminate frequency at 274.6 Hz. and delaminate frequency at 201.5 Hz. Power spectrum density at laminate frequency show laminate point has power spectrum density higher than delaminate point. Actually laminate frequency is appeared at good bonding area. So the reason which make laminate point has high power spectrum density is this point has good bonding between polyvinyl chloride sheet and fiber glass reinforced fabric. On the other hand delaminate point has poor bonding. It’s separated from each other and polyvinyl chloride only move itself when knocking is applied. This phenomenon reduce power spectrum density at laminate frequency of delaminate point but power spectrum density at delaminate frequency is increased instead. High power spectrum density is effect to high integration area. Then laminate point has high area than delaminate point. This result show laminate point can be separated from delaminate point by integration area.



(a) (b) (c)

Figure 5. Relation between frequency domain, time domain and surface bonding (a) Delaminate, (b) Partial delaminate, (c) Laminate.

Consider power spectrum at delaminate frequency. Integration area of delaminate point is higher than laminate point. This result also can be explained by effect of poor bonding. Delaminate point has poor bonding more than laminate point. So power spectrum density at delaminate frequency is increased and power spectrum density at laminate frequency is decreased. Power spectrum of partial delaminate point show power spectrum density both laminate and delaminate frequency. Integration area of partial delaminate point at laminate frequency is higher than delaminate point but lower than laminate point due to this point still has partial bonding but is not the same as laminate point.

Example of laminate and delaminate frequency is shown in figure 6. Laminate and delaminate frequency of all windsurf type are shown in table 2. Laminate frequency of all windsurf type are different. These result are conformed to sound level theory. Sound level is depend on sound frequency. High frequency interpret high sound level on the other hand low frequency interpret low sound level. There are three factor have influence to sound frequency (fullness, size and length of material). Material with high fullness is shaking with high frequency and give high sound level. This theory can be explained that laminated point which has high fullness than delaminate point is shaking with high frequency. So laminate point has high frequency than delaminate point.

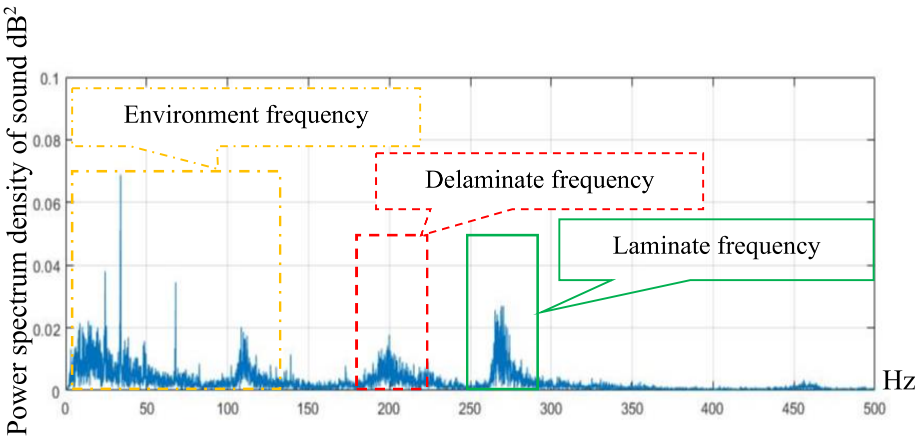


Figure 6. Laminate and delaminate frequency of windsurf 3.

All Windsurf type has the same thickness of polyvinyl chloride so the influence factor are polyvinyl chloride density, biaxial carbon reinforced fabric density and fiber glass reinforced fabric density. Windsurf 1 and windsurf 2 have the same polyvinyl chloride density but windsurf 1 has higher fiber glass reinforced fabric density. It effect to windsurf 1 has higher laminate frequency than windsurf 2 because of high fullness. Consider effect of polyvinyl chloride density. Windsurf 2 and windsurf 3 have the same density of fiber glass reinforced fabric but windsurf 2 has polyvinyl chloride density higher than windsurf 3. This factor effect to windsurf 2 has higher laminate frequency than windsurf 3. These result can be concluded that polyvinyl chloride density and fiber glass reinforced fabric density are effect to laminated frequency. Consider laminate frequency of windsurf 4 which has the highest laminate frequency. This result can be explained by effect of biaxial carbon reinforces fabric density due to windsurf 4 has the same density of polyvinyl chloride and fiber glass reinforced fabric as windsurf 3. Biaxial carbon reinforce fabric has more straightness than polyvinyl chloride and fiber glass reinforced fabric. This factor is effect to high fullness of itself and interpret highest laminate frequency.

Laminate area level from integration at laminate frequency have various value due to level of bonding. These area need to classify to be laminated or delaminate point. The important of this step is accuracy of judgement criteria. Laminate level can be explained by example of windsurf 1 as shown in figure 7 with polyvinylchloride thickness 3 mm. density 100 kg./m^3 and fiber glass reinforced fabric 0.1 g./cm^3 has laminate area until 0.28 Hz/dB^2. Surface bonding between polyvinyl chloride sheet and fiber glass reinforced fabric show good bonding until area 0.28 Hz/dB^2. When area are reduced lower than 0.28 Hz/dB^2 surface bonding is decreased. Polyvinylchloride sheet is partial separated from fiber glass reinforced fabric and show some resin on surface. This evident is able to inform that delaminate is starting occur when area is lower than 0.28 Hz/dB^2.

This parameter is utilized to established standard of laminate level by pattern recognition. The standard value for pattern recognition of windsurf 1 with polyvinylchloride thickness 3 mm density 100 kg./m^3 with fiber glass reinforced fabric 0.1 g./cm^3 is 0.28 Hz/dB^2. This explanation can be described laminate area for other windsurf type. Laminate area of other windsurf are show in table 2 and laminate pattern area of windsurf 2, windsurf 3 and windsurf 4 are shown in figure 8, figure 9 and figure 10.

Table 2. Laminate and delaminate frequency of each windsurf type including laminate area.

Windsurf type	Laminated frequency(Hz)	Delaminated frequency (Hz)	Laminated area (dB2)	Delaminate area (dB^2)	Partial delaminated area(dB^2)
Windsurf 1	301.5	202.7	>0.28	<0.28	0.28
Windsurf 2	285.4	201.5	>0.29	<0.29	0.29
Windsurf 3	274.6	201.5	>0.41	<0.41	0.41
Windsurf 4	327.4	250.1	>0.31	<0.31	0.31

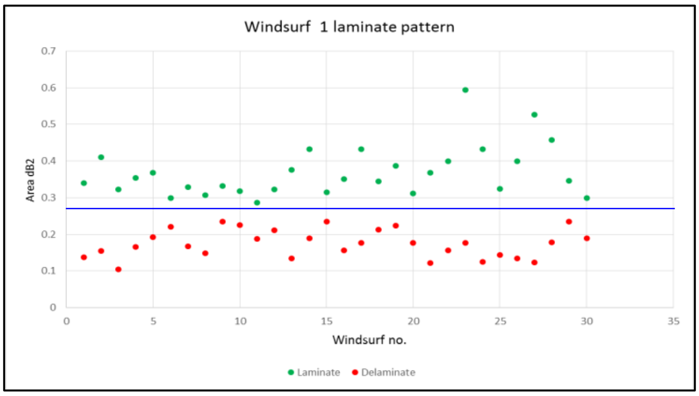


Figure 7. Windsurf 1 laminate pattern area.

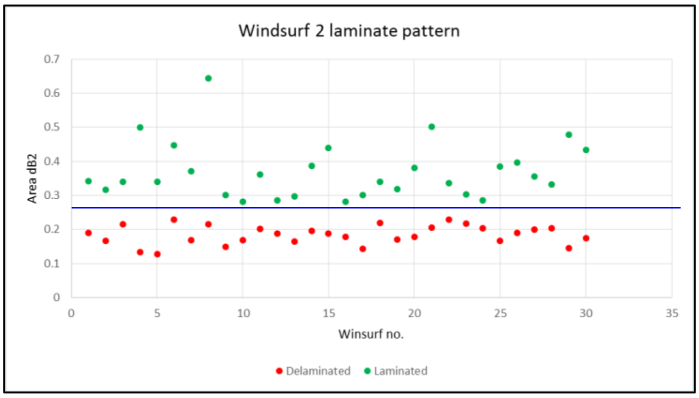


Figure 8. Windsurf 2 laminate pattern area.

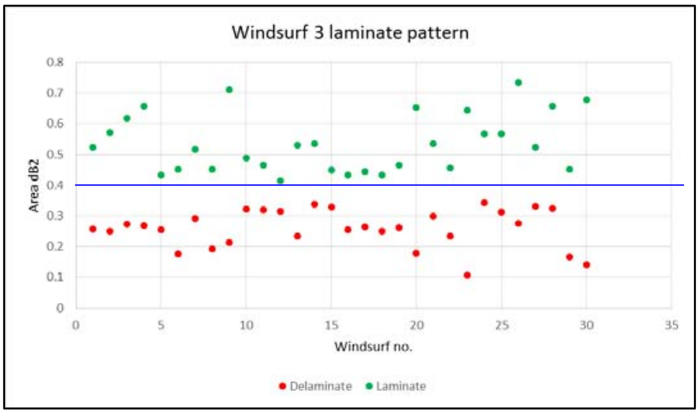


Figure 9. Windsurf 3 laminate pattern area.

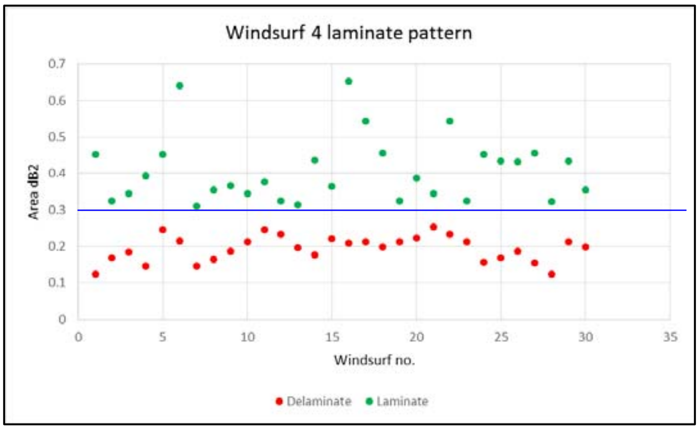


Figure 10. Windsurf 4 laminate pattern area.

4. Summary
As the result show sound sensor can be utilized to detect laminate and delaminate by applying Fast Fourier Transform to obtain frequency domain then calculate area at laminate frequency by trapezoidal rule. Area integration can be classified to laminate and delaminate point by laminate pattern area. Power spectrum density at laminate frequency have relation to type of bonding. High bonding has high power spectrum density (High area) and it is reduced when bonding is decreased. Area at laminate frequency show laminate point has the highest area. Partial laminate point has higher area than delaminate point. The result interpret laminate frequency is higher than delaminate frequency due to its fullness and density of polyvinylchloride sheet, fiber glass reinforced fabric and biaxial carbon reinforced fabric have influence to laminate frequency.

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