ISSN 1392-2114 ULTRAGARSAS, Nr.1(58). 2006.

The online ultrasonic testing system for composite strips

V. Augutis, D. Gailius, G. Balčiūnas

Institute of Metrology, Kaunas University of Technology

Abstract

Composite strips are often used as elastic elements, for example, springs. Beside stiffness, one of the most important characteristics is durability of such strips when they operate under cyclic load. This depends upon the quality of the composite, particularly on existence of the delaminations. Such qualitative properties of composites may be best evaluated using ultrasonic testing techniques.

The developed ultrasonic testing system allows on-line testing of composite strips when they moves with speeds up to 1 m/s. The operation principle of this system is based on evaluation of the ultrasonic signal propagating through the strip. The background for development of such system was development of the rotating excitation transducers (transmitters) investigation of acoustic fields, excited by these transducers, and development of the wideband ultrasonic microphones. The pulse excitation was chosen to avoid multiple reflections and propagation though the air influence.

Testing results are presented in a graphical format, showing position and size of defects in a strip.

Keywords: Composite materials, delamination, ultrasonic nondestructive testing, acoustic field, strip.

1. Introduction

Composite materials are more and more used in various areas because of their good properties. Composite strips may be used as fixing (fastening) elements or as bending stiff elements for example, springs. Their properties depend on many factors. Thus, in order to get a high quality, it is important to control parameters of such strips in production line, e.g. on-line.

One of the most important parameters of the controlled strips is their homogeneity – absence of delamination and other defects. This determines strength and durability of strips.

Main homogeneity evaluation techniques are ultrasonic based ones [1, 2]. Usually longitudinal or Lamb waves are used; reflected or trough-transmission waves techniques. Wave type, frequency range and particular testing technique selection depends on dimensions of the tested samples, ultrasonic waves attenuation, defects type and dimensions, the required testing speed and reliability.

Beside the carbon, glass and other fiber based composite materials, quite important part of composite materials is made from wood based fiber – plywood boards, strips and etc. These products may be isotropic, when several similar fiber layers are crossed perpendicularly, and anisotropic -when fiber layers are aligned mainly in one direction.

The main task of the work, particularly described in this article, was development of the fast composite plywood strips testing system, which may be used for on-line (in production line) testing of the manufactured strips, keeping in mind, that the main limiting factor of such strips strength properties are delaminations between strip layers.

2. Acoustic fields analysis

Acoustic field in a strip may be excited using an ultrasonic transducer – transmitter. Considering on-line usage of the testing equipment, it is purposeful to use the wheel like an ultrasonic transmitter and the ultrasonic receiver or receivers, which are put on the opposite strip side. Using above mentioned means it is possible to implement a technique almost identical to the through-transmission technique.

Acoustic field during measurements was of a pulse type, excited with the wheel like a piezoelectric exciting transducer. Measurements of ultrasonic field were made using a wideband microphone in the opposite side of the strip. The microphone distance from the strip was about 1 mm. The transmitter position was fixed and the microphone position was changed, scanning the opposite side of the strip. A more detailed information about the measurement and visualization technique of periodically excited acoustic fields is described in [3].

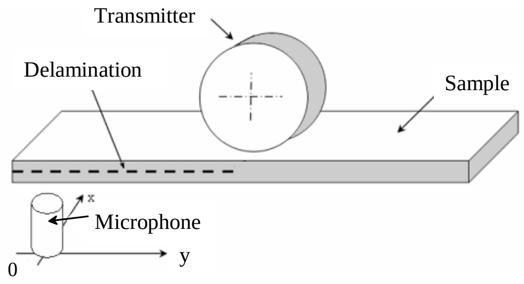
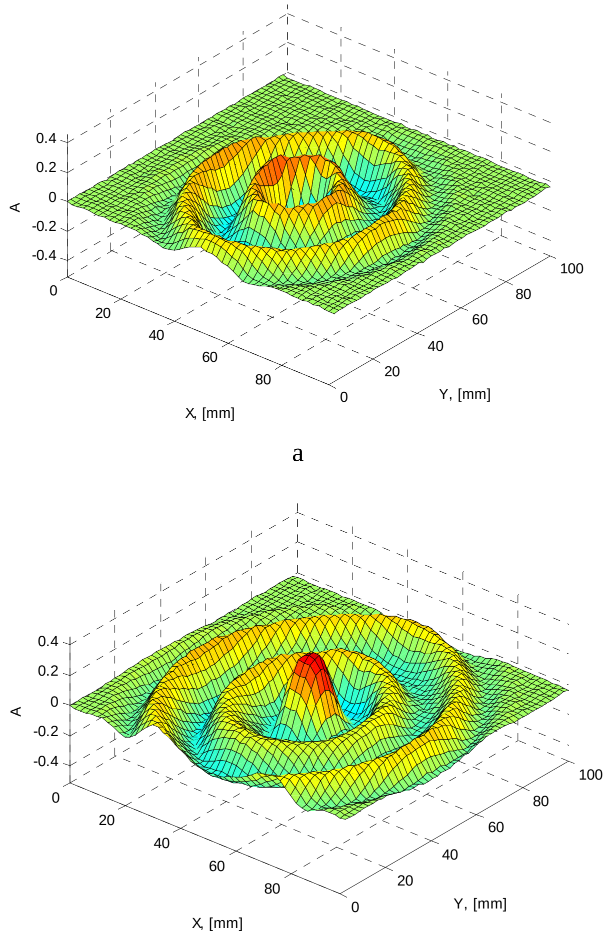


Fig. 1**. Acoustic field measurement. Structure**

Examples of acoustic field measurements are presented in Fig.2 - 4.

The axis *y* is along the strip, and the axis *x* is across the strip. The vertical axis *A* represents a surface vibrating velocity amplitude in relative units. In Fig. 2 are shown measurement results of the “frozen fields ” at 81.6 μs – (a) and 96.8 μs – (b) after the transmitter excited the pulse in the isotropic strip (width 100 mm, thickness 6 mm). The anti symmetric Lamb waves with wavelength λ = 19 mm and the propagation speed v = 0.95 km/s dominates in this example.



a

b

Fig. 2. **The acoustic field in air, close to the isotropic strip: a -47.6 μs after the excitation pulse, b – 62.8 μs after the excitation pulse**

In Fig.3 is shown the wave propagation example in the similar strip when the wave passes through the defect. The time is 28.4 μs after the excitation pulse. The defect (2 mm diameter hole) disturbs the wavefront. The similar picture is obtained when each wavefront passes through such defect.

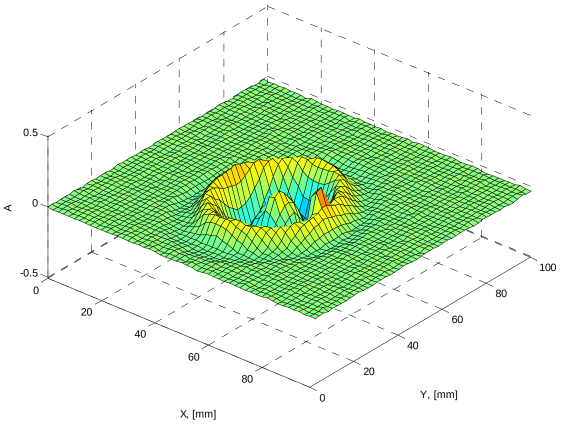
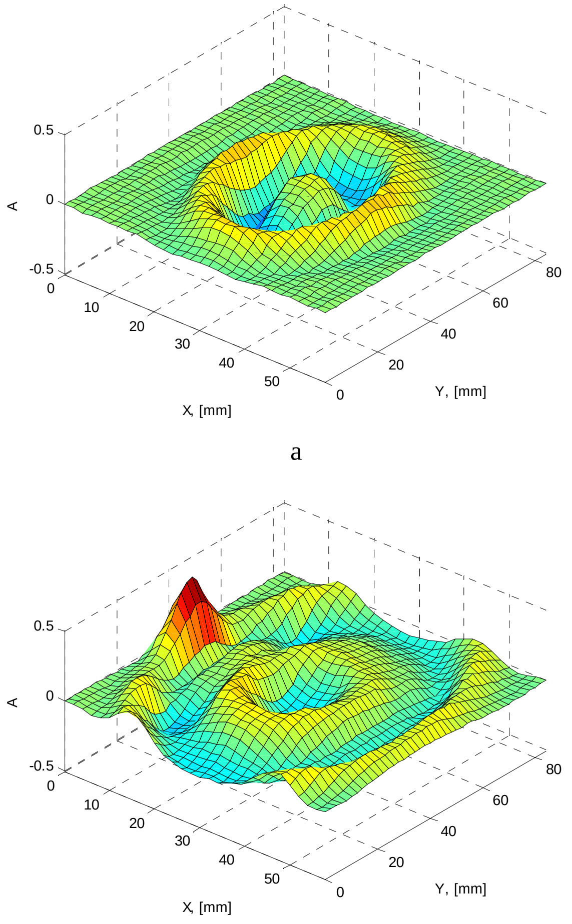


Fig.3. **The acoustic field in the isotropic strip, when the wave front passes the defect (2 mm hole)**

In Fig. 4 is presented the acoustic field in the anisotropic strip 26 μs and 46.8 μs after the excitation. The fiber direction coincides with the strip long axis and *y* axis in the picture. The strip width is 40 mm, thickness 8 mm. We can see, that wavelength in the *y* direction is about 25 mm, and along the *x* direction – about 15mm. Beside that,



a

b

Fig.4. **The acoustic field in air, close to the anisotropic strip: a – 26 μs after the excitation pulse, b – 46.8 μs after the excitation pulse**

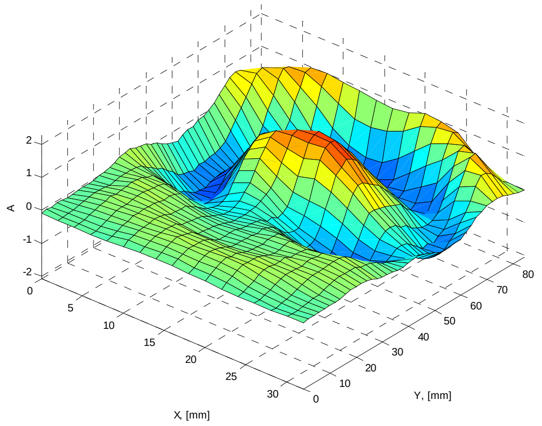


Fig.5. **The acoustic field shape at the place of delamination, when *t*=37.6 μs**

we can observe (Fig.4 b) the signal near the strip side, which passed directly through air.

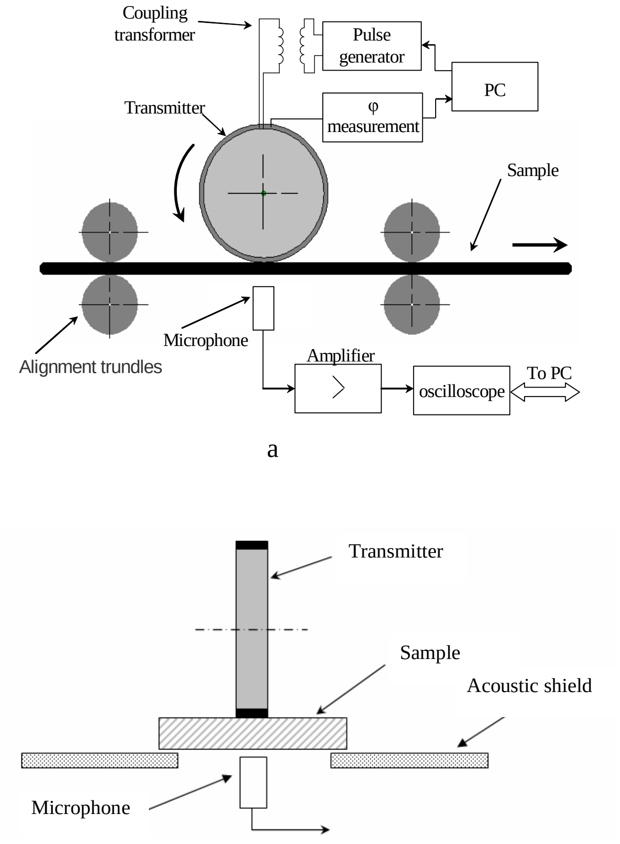
The acoustic field analysis enables to make important conclusions about the developed testing technique.

In Fig. 5 is presented the acoustic field, when the transmitter is placed directly over the delamination beginning line (as in Fig. 1.). We can see, that waves propagates in one direction, y = 50 mm from the boundary.

On the basis of analysis of acoustic fields (Fig. 3 and 5) we may conclude, that using one transmitter and several receivers it is possible to inspect a strip across entire its width.hickness 8 mm. We can see, that wavelength in the y

3. Testing system

Taking into account results of acoustic fields and requirements for the on-line system the testing system for composite strips was developed. It's structure is shown in Fig. 6. The strip transportation gear is not shown.



a

b

Fig. 6. **The testing system: a – structure, b – layout of the acoustic shields**

One of the most important units in this system is the transmitter of acoustic pulses. The proposed transmitter consists of the 60 mm diameter 4 mm thick aluminum wheel, with piezoceramic discs glued to both sides, and a rubber protector over the roll surface. The electric excitation is fed from the computer controlled pulse generator through the rotating transformer.

In order to achieve an effective excitation and a low external noise influence, the resonant narrowband transmitter was chosen with the central resonant frequency about 40 kHz.

The wideband ultrasonic microphone developed in our laboratory [4] was used for reception of excited waves. Its frequency response is shown in Fig. 7. As we can see, the frequency range is from 20 kHz to 60 kHz. This ensures a stable reception of transmitted signals. Several microphones may be positioned across the tested strip. This increases detection capability of small defects.

The transmitter, the strip, the microphone, the amplifier and the oscilloscope form the measurement channel. Its characteristics are presented in Fig. 8.

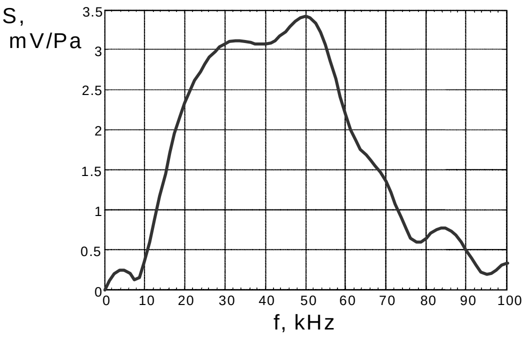
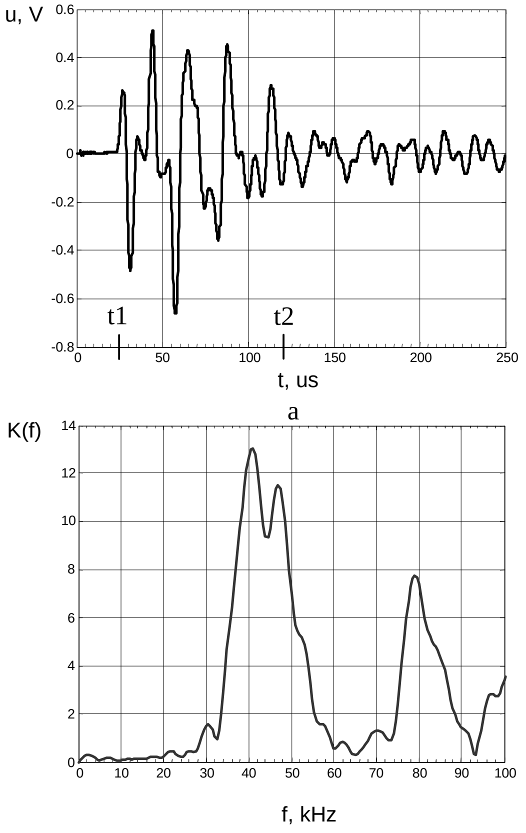


Fig. 7. **The frequency response of the receiver (microphone)**



a

b

Fig. 8. **The pulse (a) and frequency responses (b) of the measuring channel**

The transmitter wheel is fitted with the measurement transducer of the rotation angle. Pulses from this transducer are fed to the computer. Usage of this transducer allows determination of the position of the detected defect along the strip.

The used pulse excitation technique allows to eliminate influences of the reflections and propagation paths through air. For this the function *B(x)* of the received pulse response *g(t)* is calculated:

$$B(x) = \int_{t1}^{t2} |g(t)| dt \qquad (1)$$

Here x is the distance from the beginning of the strip, t_1 marks the arrival time of the received signal (i.e. 25 μs as shown in Fig. 8), t_2 depends on the strip width, 100 μs < t_2< 200 μs (120 μs in Fig. 8).

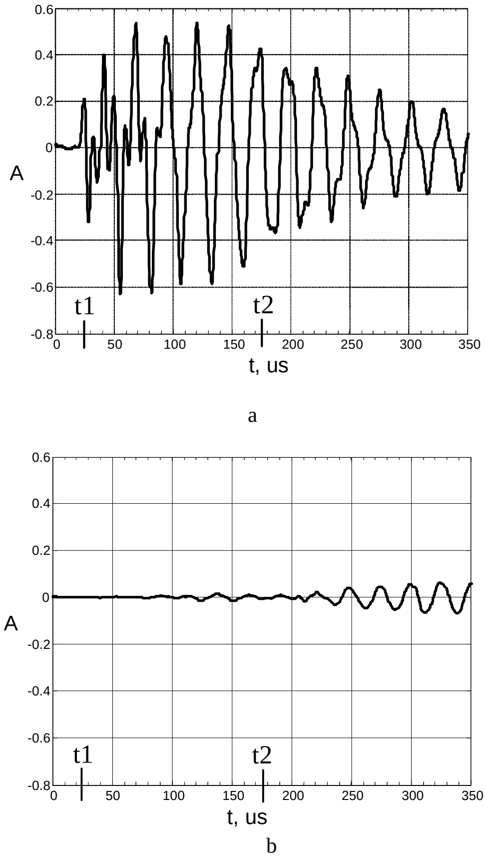
Acoustic shields were used to minimize influence of the possible direct propagation through air paths (Fig.6 b).

The main factors which limit the testing speed is the duration of the pulse response. It limits the repetition frequency of the excitation pulses. In our case the upper limit of the pulses repetition frequency was 200 Hz, what corresponds to the testing period of 5 mm along the strip, when the speed is 1 m/s.

4. Experimental results

In Fig. 9 the pulse responses of the 35 mm width and 8 mm thick strip, good and delaminated parts are shown. This matches B_a= 0.19 and B_b< 0.01, calculated for 25 μs < t< 175 μs.

As we can see, delaminations can be easily detected.



a

b

Fig. 9. **The pulse responses of the measuring channel. Strip segments: a- without defect, b- with defect**

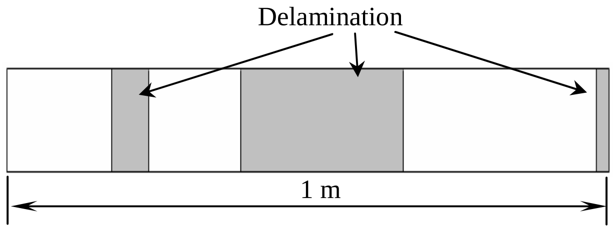


Fig. 10. **Software report example showing defects in the tested strip**

5. Conclusions

Acoustic Lamb wave fields in strips were investigated. On the basis of this investigation the system for composite strips testing was developed, which allows on-line testing of strips with speeds up to 1 m/s. The width of tested strips may vary from 25 to 80 mm, and the thickness from 8 to 12 mm.

References

1. **Krautkraemer J., Krautkraemer H.** Werkstoffpruefung mit Ultraschall. Springer Verlag, Berlin. 1986.
2. **Žukauskas E., Cicėnas V., Kažys R.** Application of air – coupled ultrasonic technique for sizing of delamination type defect in multilayered materials. Kaunas;Technologija. Ultragarsas. 2005. Vol.54. No1. P. 7-11.
3. **Augutis V., Gailius D.** Vizualization of vibroacoustic fields. Proceeding of the 3 th International Conference „Acoustical and vibratory surveilance methods and diagnostic techniques". Senlis, France. 1998. P. 873-874.
4. **Augutis V., Gailius D., Varanauskas M.** Impulse methods for measurement of characteristic of ultrasonic receivers. Proceeding of the 16 th IEEE „Instrumentation and Measurement Conference. Venice, Italy., 1999. Vol. 2. P. 866 – 869.

V. Augutis, D. Gailius, G. Balčiūnas

Kompozitinių juostų ultragarsinės kontrolės linijoje sistema

Reziumė

Kompozitinės juostos dažnai atlieka tampraus elemento (spyruoklės) vaidmenį. Veikiant ciklinei apkrovai, be standumo, viena svarbiausių šių juostų charakteristikų yra ilgaamžiškumas. Jis priklauso nuo kompozito kokybės, ypač – nuo atsisluoksniavimų, kuriems įvertinti tinkamiausiu laikytinas ultragarsinis (UG) testavimo metodas. Sukurta UG testavimo sistema, įgalinanti linijoje testuoti juostas, judančias iki 1 m/s greičiu. Jos veikimas pagrįstas UG signalo perėjimo per juostą įvertinimu. Prielaidas šiai sistemai atsirasti sudarė mūsų sukurti riedantys UG siuntikliai, tai, kad siuntiklių žadinamas akustinis laukas buvo ištirtas ir mūsų sukurti plačiajuosčiai UG ėmikliai. Pasirinktas impulsinis UG žadinimo variantas, leidžiantis eliminuoti atspindžių ir UG perėjimo per orą įtaką. Testavimo rezultatai gauti grafiniai - juostoje nurodyta defektų vieta ir jų dydis. Pateiktos siuntiklio ir ėmiklio charakteristikos, yra akustinio lauko tyrimo ir juostų bandymo pavyzdžių.

Pateikta spaudai 2006 03 28