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Experimental and FEA of the Crack Effects in a Vibrated Sandwich Plate

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Abstract: The study investigates the natural frequency of sandwich plates made from stainless steel and Teflon with crack effect. The fundamental natural frequencies are analyzed experimentally by impact hammer and numerically by ANSYS 15. The aim of the experimental investigation is the fabrication of the sandwich plate made from (stainless steel/ Teflon/stainless steel). Then 2 mm width cracks are created using Ferton power tool with 330 W and 10,000-32,000 rpm. The length of the formed cracks having 20-40 mm lengths located in different location with angles 0, 30°, 45°, 60° and 90° angle, respectively. The mechanical properties of Teflon and stainless steel such as young modulus and density are estimated. Then the fundamental natural frequencies of a clamped cracked sandwich are measured. The existence of a crack in the sandwich plate decreases the natural frequency of plate depending on the size, location and orientation angle of the crack. The experimental and numerical natural frequencyresults show that maximum value occurred in 20 mm central crack rotated by 45 while the minimum value occurred at 40 mm central horizontal crack. There is a considerable match between the results of the experimental and the ANSYS package investigations with a percentage error ranged between 4.04-7.19%.

Key words: Sandwich plate, natural frequency, crack, Teflon, natural frequency, horizontal crack

INTRODUCTION

Among the important characteristics of sandwich plates are the high strength to weight ratio, long operational life, good thermal properties, weight reduction and sound insulation. Feldhusen *et al*. (2009) estimated the load-deflection of the sandwich structure that performed under static loading condition by four-points bending tests. The results show a big agreement between the experimental work and FEM-system ALGOR of sandwich structures. Kant and Swaminathan (2001) used the Navier's techniques to evaluate and presented the natural frequency of simply-supported sandwich laminate composite. Numayr and Dwairi (2010) investigated the dynamic response by varying the materials property and geometry in (two models of three layers) sandwich plate subjected to impact loading. The study showed that the in-plane displacements of the middle surface of face layers could be neglected for sandwich plates with a flexible core. Piovar and Kormaníkova (2011) investigated the mechanical properties of the sandwich plate and their laminate facings using the FEA to compare the results. The properties of laminates are affected by the matrix through the fiber type, volume fraction and rotation angle. The angular velocities and natural frequencies are affected by the facings of sandwich plate, so, the lowest values are obtained when the facing by zinc plated steel sheets. They were slight differences between the results there was a big match. Saleh (2011) numerically investigated the buckling of the plate with a crack under the compression force using ANSYS software to calculate the critical buckling load by taking into the account the crack parameters (crack length and its location). Jweeg *et al*. (2012) summerized the presence of the crack leads to the changes in natural frequency. The natural frequencies are found from two methods: analytical solution and finite element solution by ANSIS 14.0 considering the crack size effects and their position. A big match in results was obtained when compared each to other with percentage of error not exceed 3.5%. They concluded that the natural frequency is proportional inversely with crack length or width and be higher when located at the center compared with other positioned.

Mohanan *et al*. (2013) evaluated the performance of sandwich beam with the existence of dent or deboned by using ANSYS 13.0. The study showed that deboned affects the performance more than the dent, however, both parameters have no significant influence on the natural frequencies.

Ramanujan *et al*. (2013) proposed a simple software for calculating the natural frequency of the plate. The results of this software were compared with ANSYS programming and the outcomes were so close to each other.

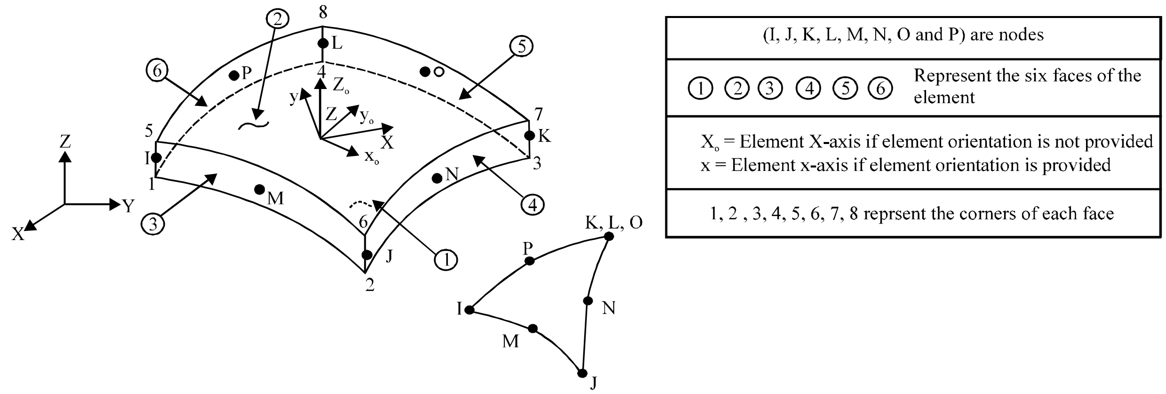

Fig. 1: Shell 281 Geometry (ANSYS 15.0 Program)

The experimental work will cover the determinations of mechanical properties and measuring the natural frequencies of a clamped plate using the impact hammer test with the presence of different sizes of the cracks. The results are confirmed using the FEM.

Numerical analysis

Element selection and modelling: FEM is adopted to analyze the problem. ANSYS (15.0) is used alongside the element (Shell 281) because it best fits with this case as shown in Fig. 1. This element consists of 8 nodes and each node has 6 DOF, i.e., (3 DOF translation along X-Z axis and 3 DOF rotation about the same axis). This element is used for modelling as it has layered applications and it contains the transverse shear deformation. The results obtained from the element have a considerable agreement when compared with First Order Shear theory. The Shell 281 was used as adiscretization element.

Mesh convergence: In this study, the total number of nodes and elements are selected to divide the geometry into segments by choosing the suitable finite element mesh. The results become more accurate once the numbers of elements in the 2-D, i.e., (X and Y directions) were increased.

When the degree of freedom is increased from 576-2046, the difference in natural frequency becomes only (0.092%). Meanwhile, when it is increased from 2046 to 4416, the difference is only a (0.004%) and no difference observed at all between DOF (4416) and DOF (7686). The natural frequency for each model is shown in Fig. 2 which indicates that DOF (4416) can be analyzed.

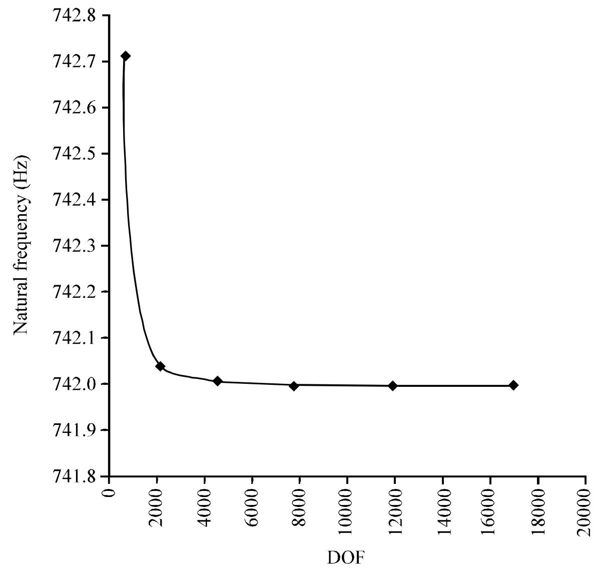

Fig. 2: Convergence study of natural frequency versus DOF for clamped plate without crack

MATERIALS AND METHODS

Experimental work: This study aims at achieving three aims. First, to outline the general steps for manufacturing the models which are later used in evaluating the young modulus of steel and Teflon alone. Second, to design and fabricate the sandwich plate from stainless steel and Teflon and trying various cases of crack. Third, to fulfil the vibration test that can be done using the impact hammer to estimate the natural frequency of sandwich plate for clamping boundary conditions with or without the crack.

Tensile test: The test specimens were cut from the plates using a CNC cutting tool machine. The first group is made of steel and the second is made of Teflon. They are divided according to dimensions as set by ASTM-E8 for stainless steel and ASTM D 638 for Teflon. The tensile test specimens are mounted vertically on a servo-hydraulic testing machine and hydraulically pulled by stroke control and large steel grips with amaximum capacity (50 kN). The results (the young modulus) are presented in Table 1 and 2.

Manufacturing the sandwich plate: The square shape sandwich plate (350×350 mm) consists of the assembly by bonding two skins of stainless steelwitha lighter Teflon layer inside which is applied to ensure that the two steel skins are separatedfrom each other. “The difference between the skins (faces) and the core in the mechanical properties is closed by the range of the faces Young modulus to the core Young modulus ratio” (Gay *et al*. 2012):

Table 1: Young Modulus for the selection materials

Materials	Young modulus (GPa)
Stainless steel	210
Teflon	2.528

Table 2: The natural frequencies of C-C-C-C sandwich plate without crack and different crack

	w_n (Hz)		
Case	Experimental	Numerical	Error (%)
Without crack	712	742.00	4.05
20 mm central horizontal crack	703	740.00	5.00
30 mm central horizontal crack	693.5	737.73	6.00
40 mm central horizontal crack	682	734.82	7.19
20 mm horizontal crack at 0.25a	710	741.22	4.21
20 mm horizontal crack at 0.75a	712	741.22	3.94
20 mm central crackat 30° angle	705	742.00	4.99
20 mm central crackat 45° angle	715	745.00	4.03
20 mm central crack at 60° angle	711	741.00	4.05
20 mm central crack at 90° angle	708	740.00	4.32

Central crack: crack in the center of the plate

$$10 \leq \frac{E_f}{E_c} \leq 100 \quad (1)$$

Where E_f and E_c are the elastic young modulus for the face and core, respectively. To determine the ratio in Eq. 1, stainless steel alloy is selected to be the constituent material of faces while Teflon represented the core. To obtain the mechanical properties of each constitution material, the tensile test is done. The faces and core are cut and a small cut has been added to each specimen using a suitable cutting tool. The Ferton power tool, with (330 W) and (10000-32000 rpm) has been used to create cracks in the plates. The crack width is equal to the thickness of cutter disc (d = 2 mm). Then, the two stainless steel faces were bonded with PVC core by cyanoacrylate adhesive and they were pressed until the adhesive material dried.

Vibration test: The test of vibration includes determining and analyzing the natural frequencies for a clamped sandwich with different crack parameters. The block diagram of the different instruments used for the measurements of natural frequencies is shown in Fig. 3 and all tools used in this test are shown in Fig. 4. The

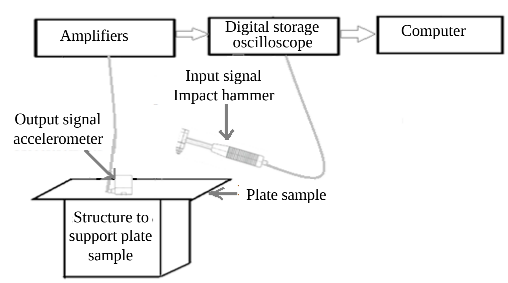

Fig. 3: Block diagram of vibration structure rig

Fig. 4: Vibration analysis test rig

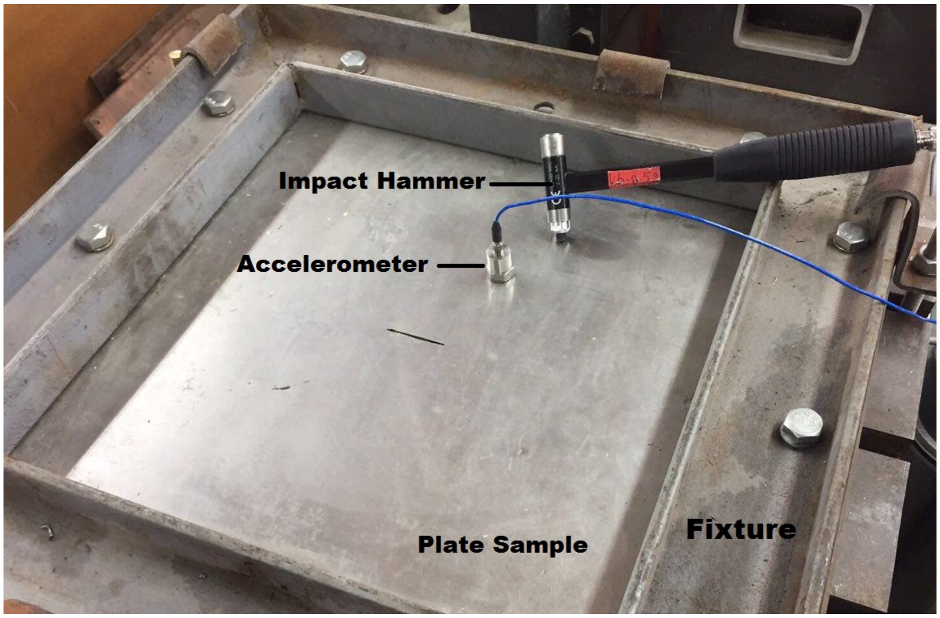

Fig. 5: Test sample with impact hammer and accelerometer

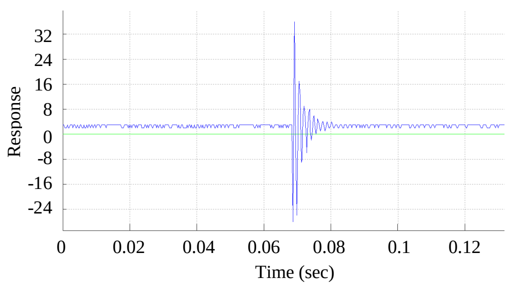

Fig. 6: The transient response of the sandwich plate (SIGVIEW)

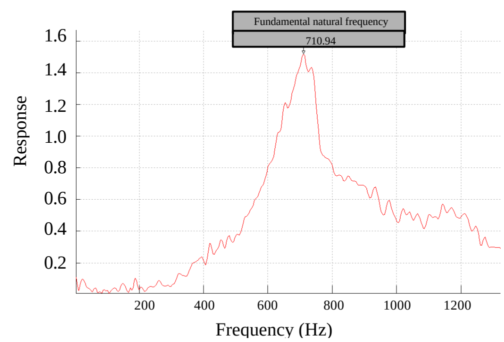

Fig. 7: FFT analysis of the response wave (SIGVIEW)

vibration test rig is composed of frame fixture which constrains the sandwich plate with clamped boundary condition. The second part is the impact hammer (Model 086C03) and stiff steel mass with many tips and contains a force sensor fixed on the end of hammer tip. The function of this sensor is to convert the impact force to an electrical signal. The third part is the accelerometer, (4371). The accelerometer is a sensor that generates an electrical signal which is directly proportioned with the second derivative of displacement with time of the vibrating sandwich plate. The accelerometer mounted to the plate by the screw thatadheres to the center of the plate. The fourth part is Amplifier 7749 which measures the signal response generated from the accelerometer and transfers the signal to the digital oscilloscope. The fifth part is the digital storage oscilloscope, Model RIGOL 1102E (100 MHz and 1 GSa/sec). This digital storage oscilloscope system can be driven by a computer (using the RS-232 serial connection). Figure 5 shows the specimen with hammer. Fig. 6 illustrates the response wave sample and Fig. 7 illustrates its FFT analysis.

RESULTS AND DISCUSSION

The results reflect the investigation of crack angle, location and size on the natural frequencies of the tested sandwitch plates experimentally and numerically.

Figure 8 shows the experimental and numerical results of natural frequency for clamped sandwich plates with central 20 mm crack . It is clear that the angle of the crack has affected the results of the fundamental natural frequencies. The maximum natural frequency occurs when the crack angle is 45° but the values of the fundamental natural frequencies are almost equal at the opposite angles like (90° and 0°) or (30° and 60°) because the sandwich plate is symmetric.

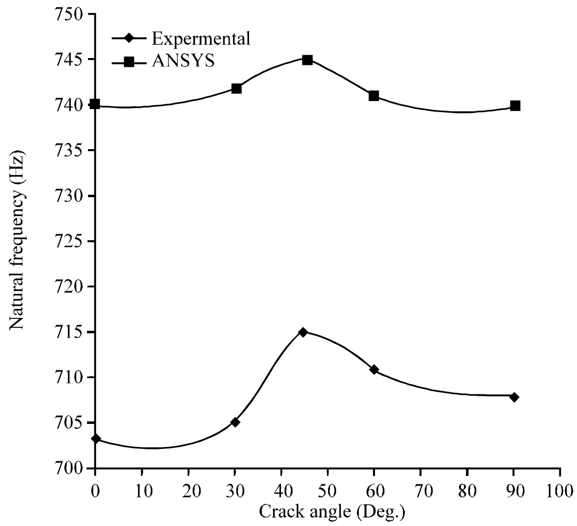

Fig. 8: The effect of 20 mm central cracks angles on natural frequency

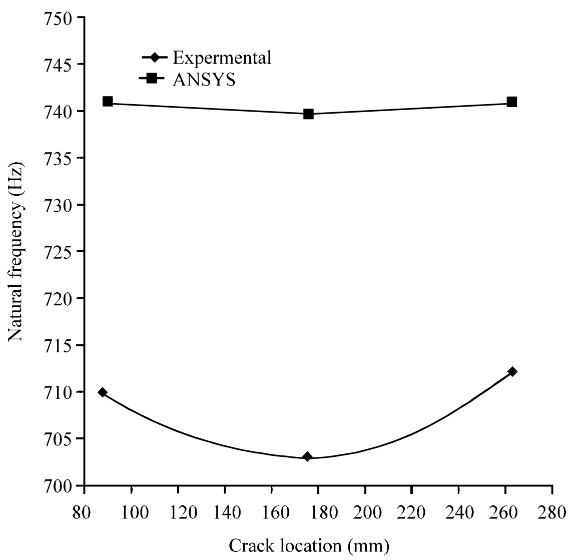

Fig. 9: The effects of 20 mm horizontal central cracks locations on natural frequency

Figure 9 shows the effect of the location of the crack on the natural frequency of the sandwich crack. The results plotted show that the sandwich plate with the central crack had the minimum value of fundamental natural frequency rather than the extreme locations of crack. This means that the presence of cracks in locations other than the center makes the sandwich plate unstable. result agrees with the result of Jweeg *et al*. (2012).

Figure 10 shows that the experimental and numerical results of the natural frequency in the horizontal cracks located at the center are proportional inversely to the crack size.

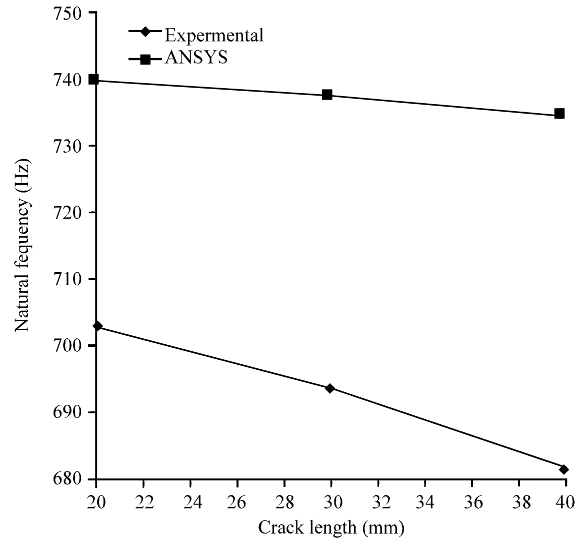

Fig. 10: The effects of central 20 mm horizontal cracks sizes on natural frequency

All the results of the natural frequencies of the cases under consideration are listed in Table 2. These results showed us that the maximum value of w_n was for the sandwitch plate with 20 mm central crack at 45° angle.

CONCLUSION

The experimental and numerical free vibration tests on the sandwich plates with different cases of the crack has come up with the following conclusions:

- The maximum value of the fundamental natural frequency occurred at a sandwich plate with a centralcrack oriented at 45° angle of rotation
- The fundamental natural frequency decreased by increasing the crack length
- The minimum value of the fundamental natural frequency is achieved when the location of the crack is at the center of the plate

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