Effect of a crack on the nonlinear behavior of a stiffened composite panel

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Abstract:

Introduction/purpose: During their lifetime, ships and aircraft are subjected to severe service and aerodynamic loads that can cause structural damage and cracking. These cracks grow and propagate over time. Extending the life of a damaged structure is a very important area of research. In this *context, the repair of composite panels is recommended to restore the performance of cracked structures.*

Methods: In order to minimize the concentration of stresses at the bottom of a crack, to stop and even to delay the propagation of this crack, this study seeks to propose a two-dimensional analysis by the software ANSYS to predict the effect of the propagation of a possible crack on the nonlinear behavior of cracked stiffened composite panels.

Results: The results from this analysis will be a very good reference for improving performance and repairing cracked composite panels using stiffeners.

Conclusion: It is recommended to provide patches for repairing cracked panels based on the modeling given in this study.

Key words: composite panels, damaged structure, crack propagation, ANSYS, concentration of stresses.

Introduction

Over the past two decades, composite materials have played an important role in the development of high-performance structures. Researchers have studied different topics in this field such as the control of cracks, vibrations, shape, buckling, and stresses in structures (Fesharaki et al, 2016).

Unfortunately, an important aspect of the behaviour of composites is their impact resistance as ships and aircraft are subjected to severe service and aerodynamic loads that can cause structural damage and cracking. During their service, cracks develop in the structures of ships and aircraft. In addition, other unexpected damaging loads or use beyond their service life exaggerate the growth of these cracks (Mall & Conley, 2009). The occurrence of cracks in the stiffened plates will reduce their ultimate compressive strength (Bayatfar et al, 2014; Shi et al, 2019; Xu et al, 2014; Xu et al, 2021), as the damage will induce earlier collapse (Shi et al, 2021). This situation constitutes a subject of great importance and a temptation to resolve it has become necessary. Therefore, repair techniques for cracked aerospace structures are needed (Mall & Conley, 2009).

To regain the initial structural capacity for which the device was designed, repairing or reinforcing the cracked or weakened part of the structure is an essential operation, thus requiring in-depth mastery. In recent years, a bonded composite patch is widely used as a very good alternative to repair cracked aerospace structures (Duong & Wang, 2007; Baker et al, 2003). In this context, to better understand the effect of crack propagation on the behavior of structures repaired by bonded patches, many studies have been carried out (Baker, 1993; Sun et al, 1996; Young et al, 1993; Jones et al, 1982; Jones et al, 1988; Rose, 1982; Tarn & Shek, 1991; Naboulsi & Mall, 1998, 1999; Denney & Mall, 1997; Heller et al, 1989; Chue et al, 1994; Xu & Guedes Soares, 2012; Xu & Guedes Soares, 2013; Shi et al, 2017). The bonded patch repair reduces the stresses near the crack, it retards or completely stops the growth of this crack. Bonded composite patch repairs offer advantages such as the absence of additional stress concentration, a higher stiffness-to-weight ratio, the ability of the patch to be formed into complex shapes, and the ability to repair irregular components (Makwana et al, 2021).

Modeling

This present research consists of modeling, using the ANSYS software, the nonlinear behaviour of a composite panel with a crack. The considered panel is simply supported on its periphery and is subjected to a bidirectional tensile loading (Figure 1).

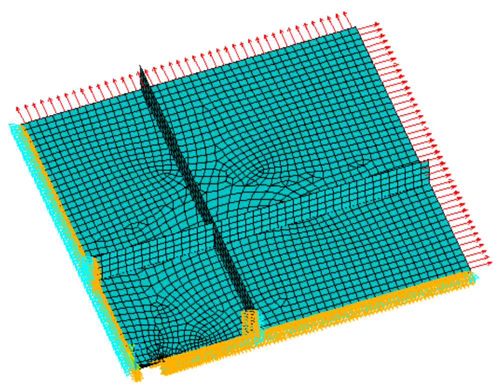

Figure 1 – Simply supported panel under a bi-axial tensil loading

The panel is made entirely of a graphite/epoxy composite with the mechanical characteristics given in Tables 1 and 2.

Table 1 – Mechanical characteristics of an epoxy graphite composite

E_1 (GPa)	E_2 (GPa)	E_3 (GPa)	G_{12} (GPa)	G_{13} (GPa)	G_{23} (GPa)	ν_{12}	ν_{13}	ν_{23}
130	10	10	4.85	4.85	3.62	0.31	0.31	0.52

Table 2 – Strengths of a graphite epoxy composite

X_T (MPa)	X_C (MPa)	Y_T (MPa)	Y_C (MPa)	S (MPa)
1933	1051	51	141	61

Ratio and the resistance index

In the ANSYS software, the resistance ratio R, also called the safety factor, is expressed by:

$$R = 1.0/\left(-\frac{B}{2A} + \sqrt{(B/2A)^2 + 1.0/A}\right) \tag{1}$$

$$A = \frac{(\sigma_x)^2}{\sigma_{xt}^f \sigma_{xc}^f} + \frac{(\sigma_y)^2}{\sigma_{yt}^f \sigma_{yc}^f} + \frac{(\sigma_z)^2}{\sigma_{zt}^f \sigma_{zc}^f} + \frac{(\sigma_{xy})^2}{(\sigma_{xy}^f)^2} + \frac{(\sigma_{yz})^2}{(\sigma_{yz}^f)^2} + \frac{(\sigma_{xz})^2}{(\sigma_{xz}^f)^2} + \frac{C_{xy}\sigma_x\sigma_y}{\sqrt{\sigma_{xt}^f\sigma_{xc}^f\sigma_{yt}^f\sigma_{yc}^f}} + \frac{C_{yz}\sigma_y\sigma_z}{\sqrt{\sigma_{yt}^f\sigma_{yc}^f\sigma_{zt}^f\sigma_{zc}^f}} + \frac{C_{xz}\sigma_x\sigma_z}{\sqrt{\sigma_{xt}^f\sigma_{xc}^f\sigma_{zt}^f\sigma_{zc}^f}} \tag{2}$$

$$B = \left(\frac{1}{\sigma_{xt}^f} + \frac{1}{\sigma_{xc}^f}\right)\sigma_x + \left(\frac{1}{\sigma_{yt}^f} + \frac{1}{\sigma_{yt}^f}\right)\sigma_y + \left(\frac{1}{\sigma_{zt}^f} + \frac{1}{\sigma_{zt}^f}\right)\sigma_z \tag{3}$$

C_{xy}, C_{yz}, C_{xz} = x-y, y-z, x-z are respectively the coupling coefficients for the Tsai-Wu theory.

The rupture will take place if this resistance report satisfies the condition $0<R<1$.

The resistance index ξ can also be expressed as:

$$\xi = A + B \tag{4}$$

If $\xi < 1$, the structure is completely safe. Otherwise, breakage is likely to occur.

Finding the critical zone

In order to find the critical values of the resistance index ξ, three points likely to have the critical stresses have been chosen. The first point is at the tip of the crack, the second one is in the position of the transverse stiffener and the third point is at the end of the panel (Figure 2). Figure 2 represents the distribution of the resistance index under a loading P=50MPa.

In order to find the most critical zone, the authors analysed the evolution of this index as a function of time for the three points chosen on the screen. The modeling results (Figure 3) show that the most important values are offered at point 1 (point of the crack). Therefore, point 1 represents more risk for the panel because of the presence of the crack which tends to propagate for resistance indices greater than the value 1. To this end, the analysis focuses on the point 1 strong constraint.

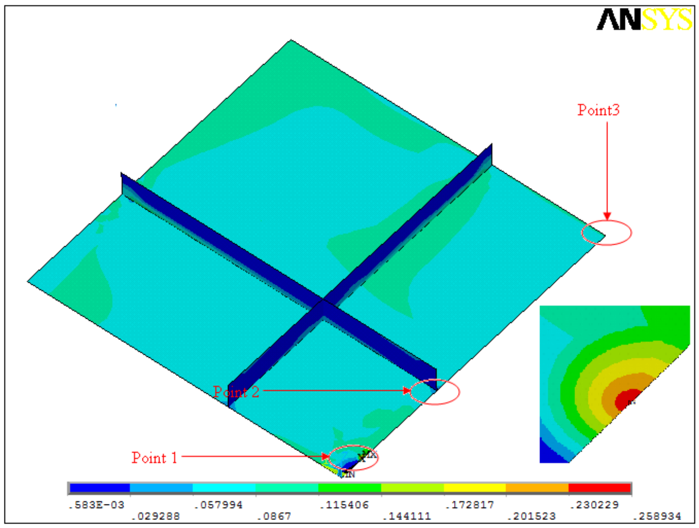

Figure 2 – Resistance index ξ of a stiffened panel for a load of 50 N/m

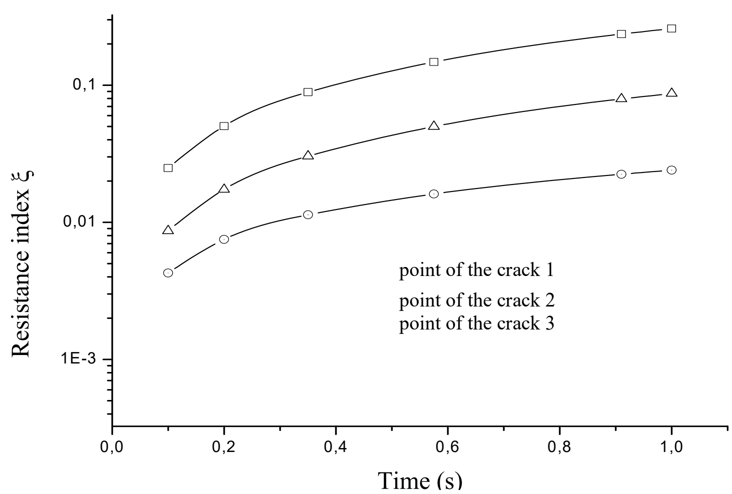

Figure 3 – Evolution of the resistance index ξ as a function of time for three points

Results and the discussion

Effect of loading

In order to see the effect of the load variation on the evolution of the resistance ratio R and the resistance index ξ, the cracked panel was subjected to several loadings.

The results obtained (Figure 4) clearly show that initially, at time t = 0.1 second, this ratio is very high and decreases as the simulation time increases. In parallel, this ratio R increases with increasing load. For example, at time t = 1s, this ratio goes from 40.225 for P=5 MPa to 0.47504 for P=400 MPa. This means that the load has a considerable effect on the evolution of the resistance ratio R.

Since the resistance index ξ is the inverse of the resistance ratio R, the curves of Figure 5 are therefore inverse of those of Figure 4. By way of example, at time t = 1s, the resistance index ξ reached = 0.02486 for a load of 5 MPa. Under the application of a load of 400 MPa, the latter is = 2.1051.

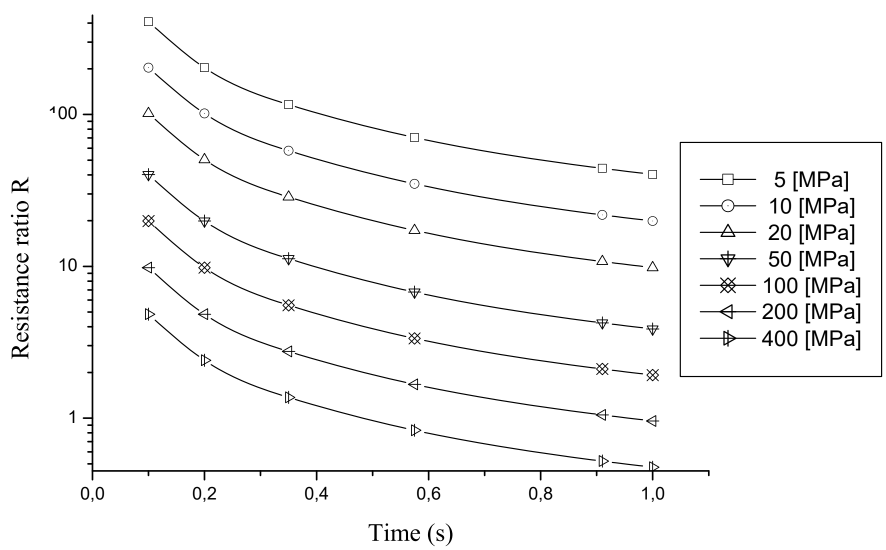

Figure 4 – Evolution of the resistance ratio R at point 1 as a function of time and the applied loading

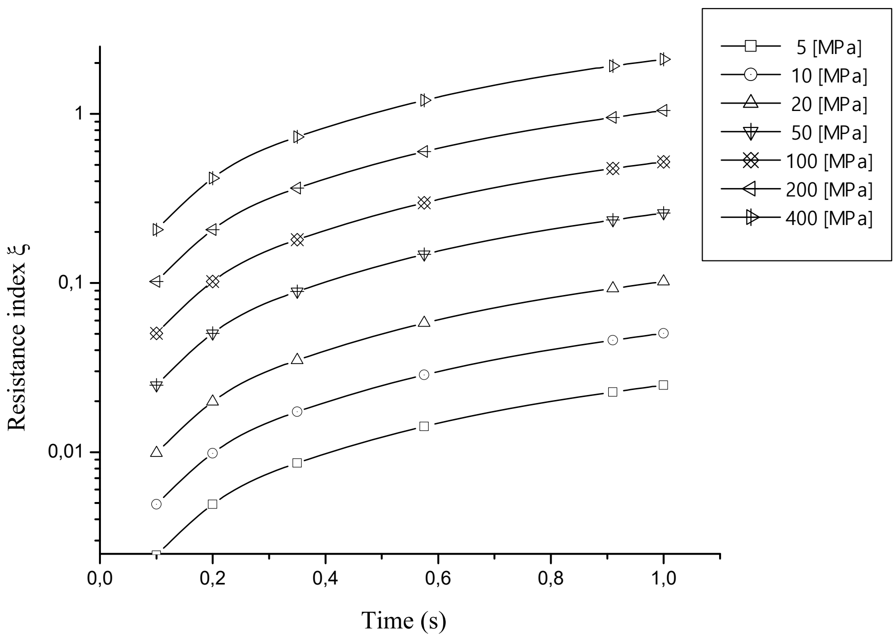

Figure 5 – Evolution of the resistance index ξ at point 1 as a function of time and the applied loading

Effect of the position of the transverse stiffeners

In order to analyse the influence of the spacing of the stiffeners on the evolution of the index and the resistance ratio, the position of the stiffeners was varied.

The stiffeners were located 40mm (Figure 6), 80mm (Figure 7) and 120mm (Figure 8) from the end of the panel.

Under a loading P= 50 MPa, it is obvious that the safety index is very high at the crack tip (Figures 6, 7, and 8). Moving away from the tip of the crack, the safety index values show that the panel is completely safe.

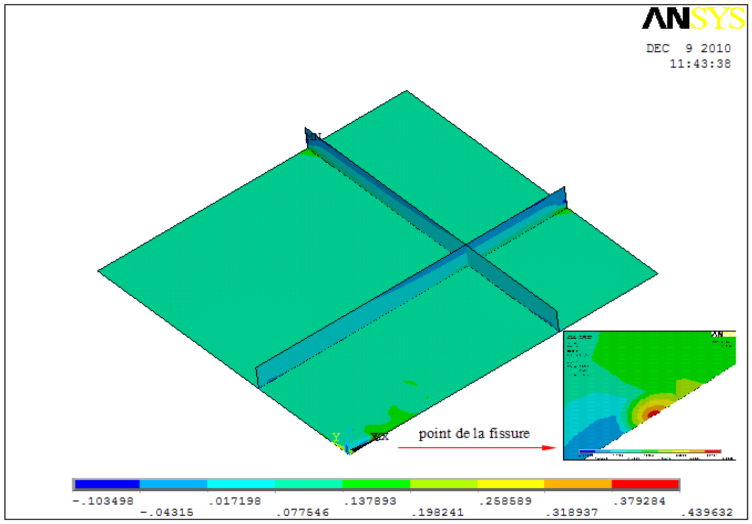

Figure 6 – Strength index for the non-linear behavior of a stiffened panel with 40mm end spacing

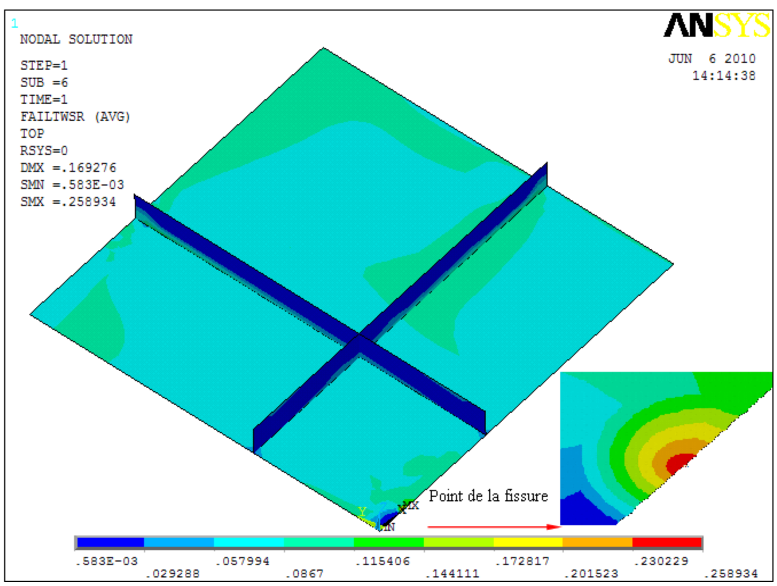

Figure 7 – Strength index for the non-linear behavior of a stiffened panel with 80mm end spacing

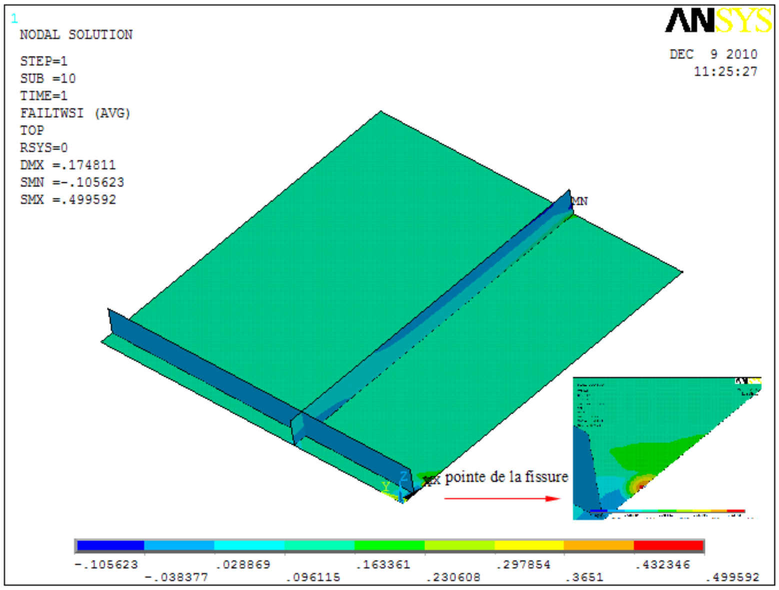

Figure 8 – Strength index for the non-linear behavior of a stiffened panel with 120mm end spacing

The results (Figure 9) provided by this modeling indicate that the position of the stiffeners considerably affects the evolution of the resistance index ξ. The latter becomes smaller with the approximation of the stiffeners to the crack tip (for t=1s, =0.00446).

So there is more security. In addition, the evolution of the resistance ratio as a function of time, for the three positions of the stiffeners, is presented in Figure 10. In this figure, the resistance ratio tends towards zero when the position of the stiffeners moves away from the crack tip.

It can therefore be concluded that bringing the stiffeners closer to the tip of the crack prevents the propagation of the cracks and ensures fairly high resistance ratios.

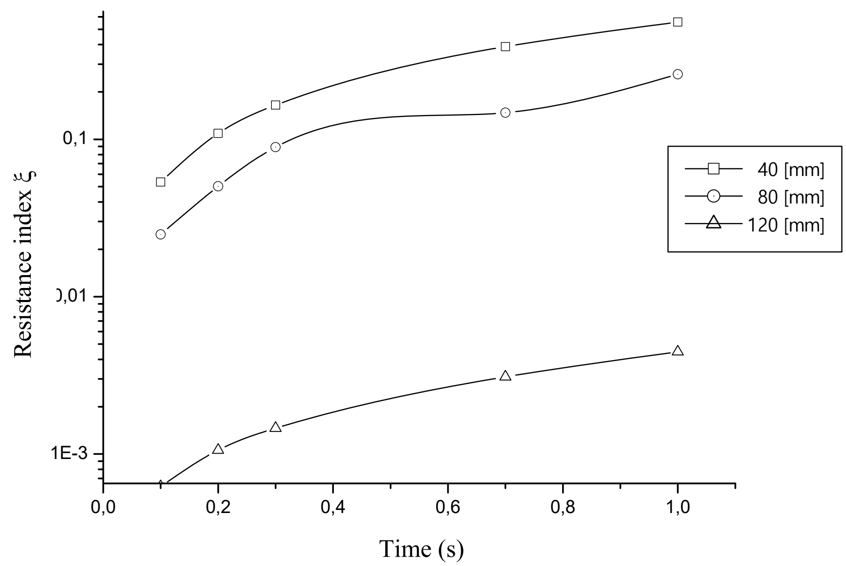

Figure 9 – Evolution of the resistance index ξ as a function of time of the cracked panel for different spacings of the transverse stiffeners

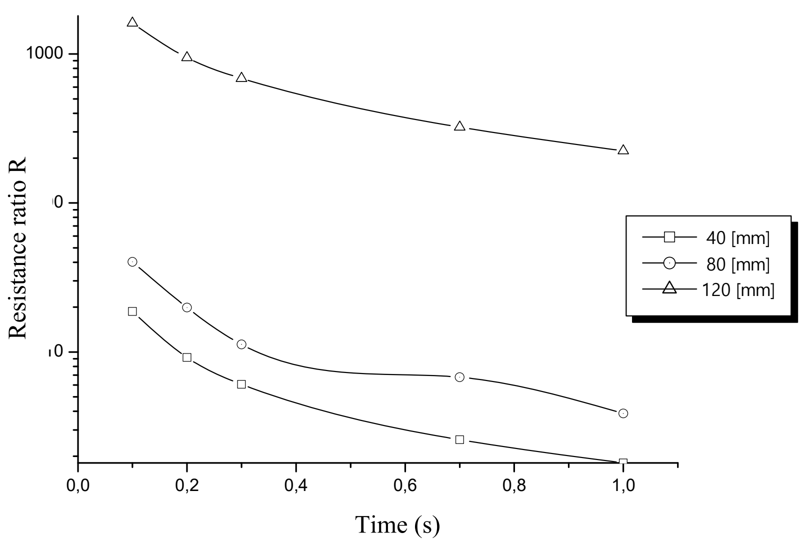

Figure 10 – Evolution of the resistance ratio R as a function of time for different spacings of the transverse stiffeners

Effect of the variation of the thickness of the stiffeners

To analyse this parameter, the stiffener thickness was changed while keeping the initial thickness of the panel constant.

From the results obtained (Figures 11 and 12), it is evident that the progressive increase in the thickness of the stiffener leads to a significant reduction in the resistance index ξ and an increase in the resistance ratio R.

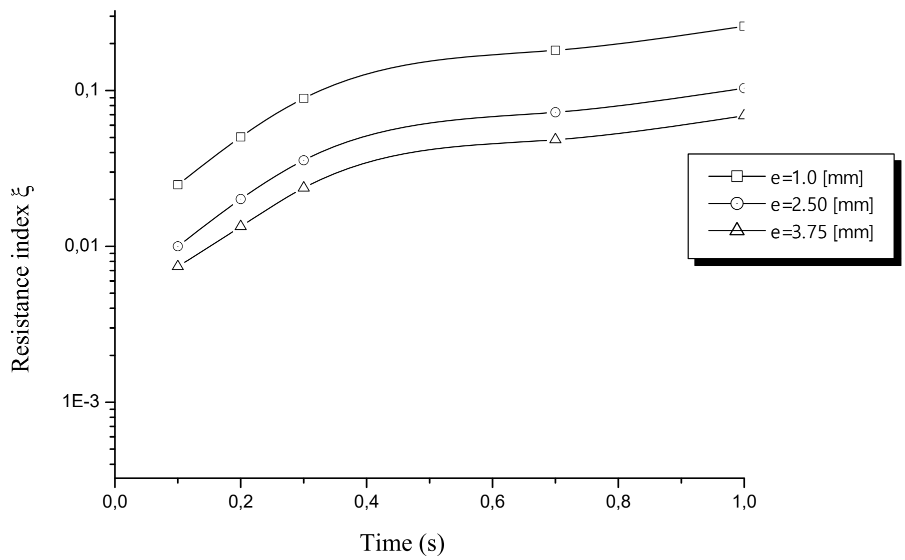

Figure 11 – Evolution of the resistance index ξ depending on the thickness of the stiffener

In Figure 11, the resistance index at t=1s goes from 0.26 for a thickness of 1 mm to 0.06 for a thickness of 3.75 mm.

On the other hand, in Figure 12, the resistance ratio at t=1s is 3.86 for a thickness of 1 mm. On the other hand, for a thickness of 3.75 mm, it increases to 14.48.

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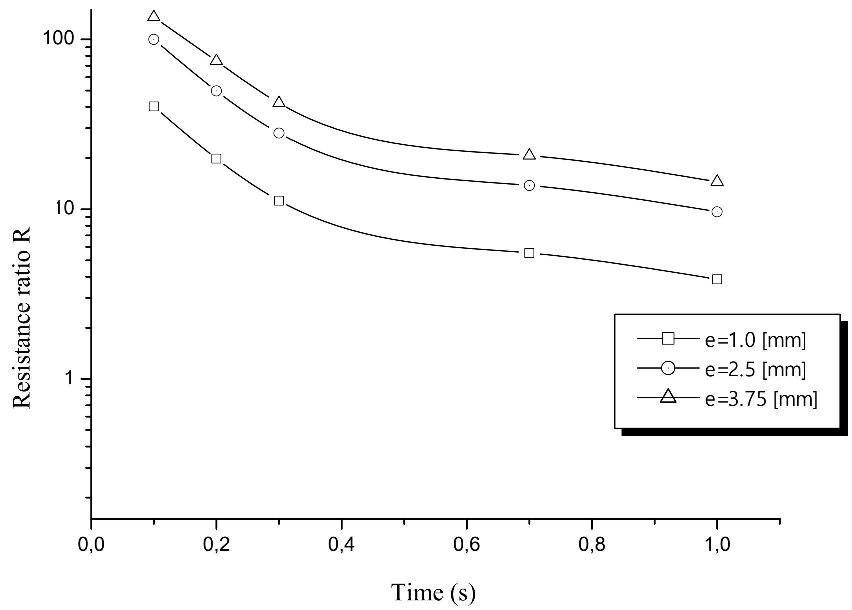

Figure 12 – Evolution of the resistance ratio R depending on the thickness of the stiffener

Conclusion

In order to follow the behaviour of a composite panel with a crack in its center in the case of large displacements, it seemed logical to carry out an analysis in the nonlinear domain.

In order to find the critical values of the index and the resistance ratio, along the panel, three points likely to have the critical stresses were chosen. The first point is at the bottom of the crack, the second one is at the level of the transverse stiffener while the third point is at the end of the panel.

From all the results provided by this modelling, it was noticed that the safety ratio increases remarkably, as a function of time, for the three chosen points. But the first point represents the most critical case because it is at the tip of the crack.

Regarding the effect of the variation of the load on the evolution of the safety ratio at the bottom of the crack, it was found that the initial state presents more risk for the panel because the resistance ratio registers to these lower values. On the other hand, the resistance index is quite important.

Following the results of this analysis, it is recommended to provide patches for the repair of cracked panels based on the presented modelling. In order to ensure structural stability, the authors intend to address panel buckling and associated stiffener-sheet separation in future research.

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Efecto de una grieta en el comportamiento no lineal de un panel compuesto rigidizado

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CAMPO: mecánica, materiales
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: Durante su vida útil, los barcos y aeronaves están sometidos a cargas aerodinámicas y de servicio severas que pueden causar daños estructurales y grietas. Estas grietas crecen y se propagan con el tiempo. Extender la vida útil de una estructura dañada es un área de investigación muy importante. En este contexto, se recomienda la reparación de paneles compuestos para restaurar el rendimiento de las estructuras agrietadas.

Métodos: Con el fin de minimizar la concentración de tensiones en el fondo de una grieta, detener e incluso retrasar la propagación de esta grieta, este estudio busca proponer un análisis bidimensional mediante el software ANSYS para predecir el efecto de la propagación de una posible grieta en el comportamiento no lineal de paneles compuestos rígidos agrietados.

Resultados: Los resultados de este análisis serán una muy buena referencia para mejorar el rendimiento y reparar paneles compuestos agrietados utilizando rigidizadores.

Conclusión: Se recomienda proporcionar parches para reparar paneles agrietados en función del modelado proporcionado en este estudio.

Palabras claves: paneles compuestos, estructura dañada, propagación de grietas, ANSYS, concentración de tensiones.

Влияние трещин на нелинейное поведение упрочненной композитной панели

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РУБРИКА ГРНТИ: 67.09.33 Бетоны. Железобетон. Строительные растворы, смеси, составы
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: В течение срока службы суда и самолеты подвергаются серьезным эксплуатационным и аэродинамическим нагрузкам, которые могут привести к повреждению конструкции и образованию трещин. Эти трещины со временем увеличиваются и распространяются. Продление срока службы поврежденной конструкции является весьма важной областью исследований. В связи с этим рекомендуется ремонт композитных панелей для восстановления эксплуатационных характеристик конструкций с трещинами.

Методы: Для того, чтобы свести к минимуму концентрацию нагрузки на дно трещины и для того, чтобы остановить или задержать распространение этой трещины в данном исследовании предлагается двухмерный анализ с помощью программного обеспечения ANSYS в прогнозировании влияния распространения трещины на нелинейное поведение порежденных упрочненных композитных панелей.

Результаты: Результаты данного исследования будут хорошим руководством для улучшения эксплуатационных характеристик и ремонта треснувших композитных панелей с использованием ребер жесткости.

Выводы: Рекомендуется использование заплаты в ремонте треснувших панелей на основе моделирования, приведенного в этом исследовании.

Ключевые слова: композитные панели, поврежденная конструкция, распространение трещин, ANSYS, концентрация нагрузки.

Утицај прслине на нелинеарно понашање ојачаног композитног панела

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ОБЛАСТ: механика, материјали
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални нуачни рад

Сажетак:

Увод/циљ: Током свог животног века, бродови и авиони су изложени изузетним експлоатационим и аеродинамичким оптерећењима која могу да изазову структурална оштећења и прслине које временом расту и шире се. Продужавање живота оштећеној структури представља веома важну област истраживања. С тим у вези, поправка композитних панела препоручује се ради враћања перформанси структурама са прслинама.

Методе: Да би се концентрација напона на дну неке прслине свела на најмању могућу меру, као и да би се зауставио, па чак и одложио раст прслине, овом студијом се предлаже дводимензионална анализа помоћу ANSYS софтвера како би се предвидео утицај раста неке прслине на нелинеарно понашање напрслих ојачаних композитних панела.

Резултати: Резултати ове студије биће добра референца за побољшавање перформанси и поправку напрслих композитних панела помоћу учвршћивача.

Закључак: Препоручује се коришћење закрпа за поправку напрслих панела на основу моделовања приказаног у овој студији.

Кључне речи: композитни панели, оштећена структура, раст прслине, ANSYS, концентрација напона.

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