Numerical investigation of crack orientation and location on the buckling stability of Aluminium stiffened plates: a study for marine and textile applications

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ABSTRACT – REZUMAT

Numerical investigation of crack orientation and location on the buckling stability of Aluminium stiffened plates: a study for marine and textile applications

This study numerically investigates the compressive buckling stability of Aluminium stiffened plates, which are critical components in marine structures and heavy machinery used in the textile industry, with a particular focus on the effects of crack orientation and eccentricity. Using linear finite element analysis (FEA), the plates were modelled with central and off-centre cracks under both clamped-free and simply supported-free boundary conditions. The analysis systematically varied the crack angle and its distance from the plate's centre to understand their influence on buckling modes and critical load coefficients. The results demonstrate a significant reduction in buckling stability due to the presence of cracks. This reduction is highly dependent on the crack's characteristics, as the most critical case for buckling occurs when the crack is oriented parallel to the stiffeners (at a 90° angle), significantly lowering the buckling load for both boundary conditions. Furthermore, the research findings of this article reveal that crack eccentricity plays a crucial role. For simply supported-free plates, the buckling load is most critically reduced when the crack is closer to the loaded edge (e_y=80mm), while for clamped-free plates, the opposite is true. Quantitatively, a crack can decrease the buckling coefficient by approximately 11% in clamped-free plates and 17% in simply supported-free plates in the most critical configurations. This research provides essential insights into the failure mechanisms of stiffened plates, emphasising the importance of considering crack parameters in structural design and maintenance to ensure the integrity of marine structures.

Keywords: *buckling stability, 1100 Aluminium alloy, stiffened plate, centre and off-centre cracks, FEM method, textile industry*

Investigarea numerică a orientării și localizării fisurilor asupra stabilității la flambaj a plăcilor rigidizate din aluminiu: studiu pentru aplicații marine și textile

Acest studiu investighează numeric stabilitatea la flambaj compresiv a plăcilor rigidizate din aluminiu, care sunt componente critice în structurile marine și în utilajul greu din industria textilă, cu un accent special pe efectele orientării și excentricității fisurilor. Folosind analiza liniară cu elemente finite (FEA), plăcile au fost modelate cu fisuri centrale și descentrate, atât în condiții de fixare liberă, cât și în condiții de susținere liberă. Analiza a variat sistematic unghiul fisurii și distanța acesteia față de centrul plăcii pentru a înțelege influența lor asupra modurilor de flambaj și a coeficienților de sarcină critici. Rezultatele demonstrează o reducere semnificativă a stabilității la flambaj datorită prezenței fisurilor. Această reducere depinde în mare măsură de caracteristicile fisurii, deoarece cazul cel mai critic pentru flambaj apare atunci când fisura este orientată paralel cu rigidizările (la un unghi de 90°), reducând semnificativ sarcina de flambaj pentru ambele condiții de margine. În plus, rezultatele cercetării din acest articol relevă faptul că excentricitatea fisurii joacă un rol crucial. Pentru plăcile cu sprihin liber, sarcina de flambaj este redusă în mod critic atunci când fisura este mai aproape de marginea încărcată (e_y=80 mm), în timp ce pentru plăcile cu fixare liberă, este valabil opusul. Din punct de vedere cantitativ, o fisură poate reduce coeficientul de flambaj cu aproximativ 11% în plăcile cu fixare liberă și cu 17% în plăcile cu susținere liberă în configurațiile cele mai critice. Această cercetare oferă perspective esențiale asupra mecanismelor de defectare a plăcilor rigidizate, subliniind importanța luării în considerare a parametrilor de fisuri în proiectarea și întreținerea structurale pentru a asigura integritatea structurilor marine și utilajului greu din industria textilă.

Cuvinte-cheie: *stabilitate la flambaj, aliaj de aluminiu 1100, placă rigidizată, fisuri centrate și descentrate, metoda FEM, industria textilă*

INTRODUCTION

Plates are the most important components of marine structures, bridges, and constructions, as well as heavy machinery, which are easily susceptible to buckling under compressive loading. If plate thickness is sufficiently small compared to other plate sizes, buckling under compression, shear, or tension can occur. Therefore, it is important to increase the plate's load-bearing capacity. One of the most useful ways is to reinforce the plates by using stiffeners. Stiffeners are transverse or longitudinal beams that are attached to the main plates to increase their strength. Cracks can be easily produced due to imperfections in manufacturing, such as imperfections in welding, corrosive environments, or fatigue loading. The presence of cracks can decrease plate stability. When plates contain defects such as cracks, investigation of the buckling phenomenon becomes more necessary, and it can be intensified due to the existence of cracks. Therefore, the effect of cracks on buckling stability is inevitable, and it is important to study the buckling behaviour of these plates to improve their bearing capacity for the safety assessment of the structures.

While a number of studies have investigated the buckling of cracked plates, a significant gap remains in the literature regarding the specific influence of off-centre cracks on the stability of stiffened plates. Existing research, such as that by Roberto Brighenti [1], has primarily focused on the buckling of unstiffened, cracked thin plates under various loads. Using the stress field of a deep beam, he suggested a rough theoretical method for calculating the critical load of tensioned plates. He demonstrated that the primary effect of cracks is the decrease of buckling compressive stress multipliers and that the presence of a crack in a compressed plate is advantageous (independent of the orientation of the break) since it raises the compressive buckling load in comparison to the uncracked case. It has been observed that the tension critical load multipliers tend to be greater than the corresponding compressive ones. Brighenti [2] also studied the fracture and buckling behaviour of broken tin plates under shear pressure in 2010. They demonstrated that, in real-world applications, only very low values of the critical stress-intensity factor can cause fracture failure rather than buckling in fractured plates under shear loading. Using finite element analysis, Alinia et al. [3] examined the impact of central cracks on the remaining strength and stiffness degradation of shear panels. They discovered that the buckling behaviour in shear panels may vary depending on the length and angle of cracks.

Seifi and Kabiri looked at how lateral pressure affected the buckling of plates having a central crack [4]. In contrast to the case with simply lateral support, they investigated how lateral compressive load decreases the critical buckling load while lateral tensile load raises it, and how lateral load usually doesn't alter the first mode.

Heo et al. [5] investigated the buckling of plates with edge and centre cracks using peridynamics. To ascertain the critical buckling loads, they employed the finite element program ANSYS. When peridynamic data were compared to experimental and numerical results, there was good agreement among the different approaches. Using both theoretical and practical approaches, Guz and Dyshel [6] examined the buckling of panels with centre and off-centre cracks under strain. The tensile and compressive buckling of plates that are weakened by core cracks was examined by Sih and Lee [7]. They demonstrated how the existence of core cracks affects the bearing capacity of plates. The buckling phenomenon in composite plates, including core cracks under compression, tension, and shear loading, was investigated by Nasirmanesh and Mohammadi [8]. They employed the conventional XFEM and FEM techniques. They demonstrated the greater accuracy of the XFEM technique. Using phase field theory and the finite element approach, Minh et al. [9] examined the stability of functionally graded materials under compressive loads.

The ultimate strength of steel plates with edge and central cracks under uniaxial compressive and tensile stresses was investigated by Paik et al. [10]. A numerical investigation on the failure mode and buckling stability of clamped or simply supported plates with small to big size cracks was conducted by Memarzadeh et al. [11, 12]. They discovered that the buckling of plates is more affected by significant cracks. Using a computational approach, Khedmati et al. [13] investigated the buckling of simply supported plates with tiny off-centre cracks.

A cracked thin steel panel subjected to successive tensile to compressive stress was shown to exhibit buckling and collapse behaviours by Sujiatanti et al. [14], both experimentally and statistically. They discovered that buckling behaviour can be impacted by the existence and extent of cracks. Rad and Panahandeh-Shahraki [15] investigated the buckling of functionally graded plates under strain. Using a single-domain Ritz technique, Milazzo et al. [16] investigated the buckling and post-buckling of broken plates. Usinga sell-solid mixed finite element approach, Tanaka et al. [17] examined the buckling and collapse of cracked panels under a series of tensile to compressive pressures. Their findings demonstrate that the buckling and collapse behaviour of cracked panels is significantly impacted by the crack opening and closure.

Seifi and Khodayari [18] also studied the buckling of a cracked thin plate under full and partial compression edge loading experimentally and numerically. They showed that the buckling load decreases by increasing the angle of the crack and the load. Also, perpendicular cracks to the loading cause a greater reduction in buckling load. Taheri and Memarzadeh [19] numerically and experimentally studied the compressive buckling stability of plates with centre and off-centre cracks. They found that the effect of crack eccentricity largely depends on the plate's support type, and the plates with two opposite free edges and larger cracks cause lower buckling stability. Sadek and Tawfik [20] numerically analysed the buckling behaviour of a steel-stiffened plate with a central crack. They found that a transverse crack is more stable than a longitudinal crack. Gullizi et al. [21] studied the buckling behaviour of cracked stiffened panels by the extended Ritze formulation. They compared their results with finite element simulations to show the accuracy of their approach.

The buckling of cracked plates, particularly that kind of plates with central cracks, has been the subject of numerous studies, which is remarkable. Researchers and designers continue to be concerned about the buckling behaviour of stiffened plates with off-centre cracks because there aren't enough studies in this field. Furthermore, no research has yet been done on the buckling stability of off-centre fractured stiffened plates with varying crack angles. However, these findings do not fully address the complex interaction between crack location, stiffeners, and buckling behaviour in a practical engineering context. This research study fills this critical gap by systematically analysing how off-centre cracks and their angular orientation affect the critical buckling load of Aluminium stiffened plates, a key structural component in marine applications and heavy machinery in the textile industry. By examining these parameters simultaneously, the study provides a more comprehensive and directly applicable dataset for the design and maintenance of real-world structures. This research's unique focus on stiffened plates with eccentric cracks, a scenario frequently encountered in practice, establishes the clear necessity and novelty of this work.

This study presents a novel and comprehensive numerical investigation into the buckling behaviour of Aluminium stiffened plates containing small cracks. Unlike prior research, this research study simultaneously analyses the influence of multiple crack parameters, including angle, off-centre location, and their interaction with different boundary conditions (clamped-free and simply supported-free) on buckling stability. This study provides new, quantitative data on the critical buckling load reduction caused by these cracks. By exploring this complex interplay, the findings of this study offer valuable insights into the specific failure mechanisms and provide a more realistic assessment of structural integrity, which is essential for the design and maintenance of marine structures and heavy machinery in the textile industry. This integrated approach significantly advances the understanding of how localised damage affects the global stability of stiffened plates.

According to fracture mechanics analysis of cracked plates, the stresses around the crack tip (figure 1) can be obtained as below [22]:

$$\sigma_{xx} = \sigma\sqrt{\frac{a}{2r}}\cos\frac{\theta}{2}\left[1 - \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right] \quad (1)$$

$$\sigma_{yy} = \sigma\sqrt{\frac{a}{2r}}\cos\frac{\theta}{2}\left[1 + \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right] \quad (2)$$

$$\sigma_{xy} = \sigma\sqrt{\frac{a}{2r}}\sin\frac{\theta}{2}\cos\frac{\theta}{2}\cos\frac{3\theta}{2} \quad (3)$$

Corresponding to the above equations, the values of stresses approach infinity in the vicinity of the crack tip, as r approaches zero.

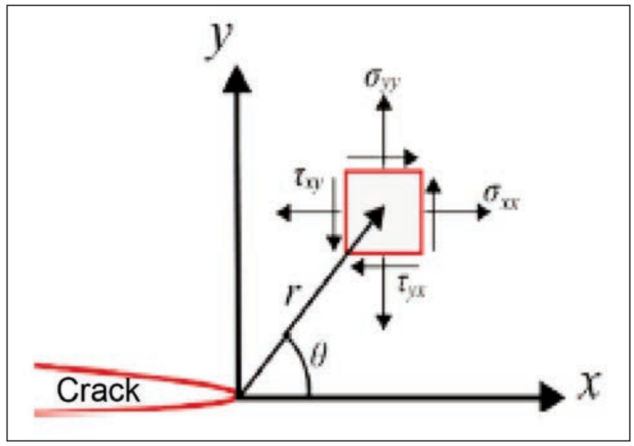

Fig. 1. Stresses around the crack tip [22]

Numerical approach

In the present study, plates were modelled and meshed in Abacus software using the finite element method. Eigenvalues and buckling coefficients were obtained by this method to show the influence of changing parameters, such as the location and direction of cracks, on the plate's buckling stability.

Determination of buckling coefficient

For a plate under uniform compressive loading, the analytical solution for the critical loads N_{cr} can be defined as follows:

$$k = \frac{N_{cr}\, w^2}{\pi^2 E t^3} 12(1 - \nu^2) \quad (4)$$

where k is the buckling coefficient, w is the width of the plate, and t is the thickness of the plate, E and ν are the modulus of elasticity and Poisson's ratio.

MATERIAL PROPERTIES

Nowadays, the utilisation of Aluminium and its alloys is being increased due to the benefits which they provide for marine and aerospace structures. The flexibility, high strength-to-weight ratio, high melting point, and corrosion resistance of Aluminium alloys have caught designers and engineers' attention. In the following table 1 mechanical properties of 1100 Aluminium are shown.

In this article, a sheet of 1100 Aluminium alloy with a length of 240 mm, a width of 240 mm and a thickness

Table 1

MECHANICAL PROPERTIES OF 1100 ALUMINUM

σ_y (MPa)	σ_u (MPa)	E (GPa)	ν
120	170	63.9	0.33

Table 2

DIMENSIONS OF T SECTIONS

l (mm)	h_w (mm)	t_w (mm)	b_f (mm)	t_f (mm)
240	25	1.5	20	1.5

of 1.5 mm has been studied in different cases. Also, dimensions of stiffeners (stiffeners with T section) are shown in table 2.

MODELLING

Numerical modelling has been done by finite element method with Abaqus software. Plates including cracks with the length of $2a = 60$ mm in different angles (0°, 30°, 60°, and 90°) with three different eccentricities (0, 40, 80) are investigated for both simply (SFSF) supported plates (two opposite edges are simply supported and the other edges are free) and clamped (CFCF) supported plates (two opposite edges are clamped and the other edges are free). Overall, 24 cases are modelled and demonstrated. The plates are meshed with an element S4R containing 6889 (83* 83) elements. Figure 2 shows different boundary conditions.

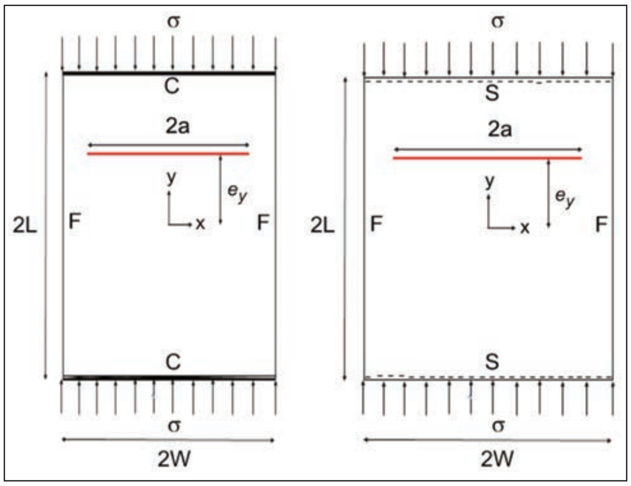

Fig. 2. Different boundary conditions

NUMERICAL SOLUTION

Buckling of simply supported stiffened plate (SFSF) and clamped stiffened plate (CFCF) with different angles of centre and off-centre cracks

For numerical analyses, a plate with a length and width of 240 mm has been modelled. The right and the left sides of the plate are free, and the top and the bottom of the plate are simply supported. After modelling and meshing, the critical buckling load (N_{cr}) which is the smallest value of eigenvalues (mode 1), has been obtained. The buckling coefficient (k) is evaluated from equation 4. The following tables 3–8 describe the results.

RESULTS AND DISCUSSION

In this section, the buckling behaviour of cracked stiffened plates with different boundary conditions will be investigated.

Result validation

To validate the numerical approach, a plate of identical size and material properties to that experimentally investigated by Taheri and Memarzadeh [19] was

Table 3

NUMERICAL RESULTS OF THE FIRST BUCKLING MODE WHEN THE STIFFENED PLATE IS SIMPLY SUPPORTED

Crack inclination	Crack eccentricity	Buckling load	Buckling coefficient
0°	0	13169	15.896
	40	13523	16.323
	80	13526	16.326
30°	0	13206	15.940
	40	13357	16.122
	80	13227	15.966
60°	0	13060	15.764
	40	13274	16.022
	80	13518	16.317
90°	0	12913	15.587
	40	12404	14.972
	80	12369	14.930

Table 4

NUMERICAL RESULTS OF THE SECOND BUCKLING MODE WHEN THE STIFFENED PLATE IS SIMPLY SUPPORTED

Crack inclination	Crack eccentricity	Buckling load	Buckling coefficient
0°	0	14707	17.752
	40	14989	18.092
	80	15195	18.341
30°	0	14806	17.872
	40	14985	18.088
	80	15195	18.258
60°	0	14905	17.991
	40	14998	18.103
	80	15192	18.337
90°	0	14990	18.094
	40	14979	18.080
	80	14889	17.972

Table 5

NUMERICAL RESULTS OF THE THIRD BUCKLING MODE WHEN THE STIFFENED PLATE IS SIMPLY SUPPORTED

Crack inclination	Crack eccentricity	Buckling load	Buckling coefficient
0°	0	17482	21.102
	40	17568	21.206
	80	17468	21.085
30°	0	17469	21.086
	40	17563	21.199
	80	17406	21.010
60°	0	16740	20.206
	40	17232	20.800
	80	17464	21.080
90°	0	16035	19.355
	40	16903	20.403
	80	17179	20.736

Table 6

NUMERICAL RESULTS OF THE FIRST BUCKLING MODE WHEN THE STIFFENED PLATE IS CLAMPED			
Crack inclination	**Crack eccentricity**	**Buckling load**	**Buckling coefficient**
0°	0	16313	19.689
	40	16382	19.764
	80	16421	19.819
30°	0	16360	19.745
	40	16379	19.768
	80	16386	19.776
60°	0	15808	19.079
	40	16187	19.535
	80	16390	19.781
90°	0	15161	18.498
	40	15582	18.806
	80	16364	19.750

Table 7

NUMERICAL RESULTS OF THE SECOND BUCKLING MODE WHEN THE STIFFENED PLATE IS CLAMPED			
Crack inclination	**Crack eccentricity**	**Buckling load**	**Buckling coefficient**
0°	0	16566	19.994
	40	16990	20.501
	80	17219	20.782
30°	0	16567	19.994
	40	16816	20.295
	80	16844	20.329
60°	0	16647	20.091
	40	16503	19.918
	80	16651	20.053
90°	0	16656	20.102
	40	16571	20.000
	80	16599	20.033

selected. Their original study focused on the buckling stability of this plate under a specific clamped-free-clamped-free (CFCF) boundary condition. The results of this study, obtained using Abaqus software, demonstrate strong agreement with these published experimental findings, as detailed in table 9. This

Table 8

NUMERICAL RESULTS OF THE THIRD BUCKLING MODE WHEN THE STIFFENED PLATE IS CLAMPED			
Crack inclination	**Crack eccentricity**	**Buckling load**	**Buckling coefficient**
0°	0	16926	20.428
	40	17233	20.793
	80	17623	21.269
30°	0	17099	20.637
	40	17539	21.168
	80	17972	21.693
60°	0	17493	21.115
	40	17731	21.402
	80	17907	21.720
90°	0	17743	21.417
	40	17744	21.418
	80	17721	21.390

correlation provides confidence in the accuracy of the current computational model.
Crack relative length is the following:

$$\frac{2a}{w} = 0.25 \qquad (5)$$

where w is the plate width and $2a$ is the crack length. For both experimental and numerical investigations, the same material, size, and boundary conditions have been considered.

Stiffened plate with SFSF edges

Figure 3 shows the first buckling coefficient modes of the stiffened plate when the crack is located at different eccentricities in SFSF plates. As shown in the stiffened plate with SFSF edges, the lowest buckling coefficient occurs at $\theta = 90°$ and $e_y = 80$ mm. Therefore, the most critical case happens when the crack is parallel with the stiffeners. In other words, as the crack becomes vertical with respect to the loading edge (and also closer to the loading edge), the buckling load decreases. Figures 4 and 5 show the second and the third buckling modes, respectively. Also, figure 6 shows buckling mode shapes for stiffened plates with centric cracks at different angles.
A crack oriented at $\theta = 90°$ is perpendicular to the applied compressive load and parallel to the stiffeners.

Table 9

COMPARISON OF EXPERIMENTAL DATA WITH NUMERICAL DATA						
BC: CFCF						
Crack inclination	**Eccentricity (mm)**	**Experimental result**		**Numerical result**		
		Buckling load (N)	**Buckling coefficient**	**Buckling load (N)**	**Buckling coefficient**	**Difference (%)**
(No crack)	-	3248	3.916	3242.4	3.913	0.18
0°	0	2664	3.211	2995.2	3.615	12.42
0°	40	2907	3.504	3144	3.794	8.15
0°	80	2961	3.570	3162.3	3.816	6.7

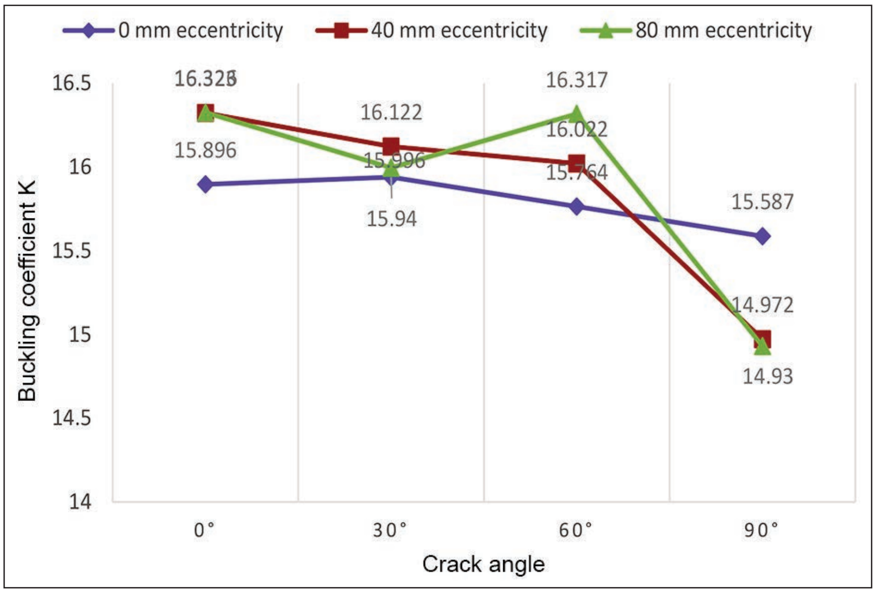

Fig. 3. First buckling mode of SFSF stiffened plate concerning crack angle at different eccentricities

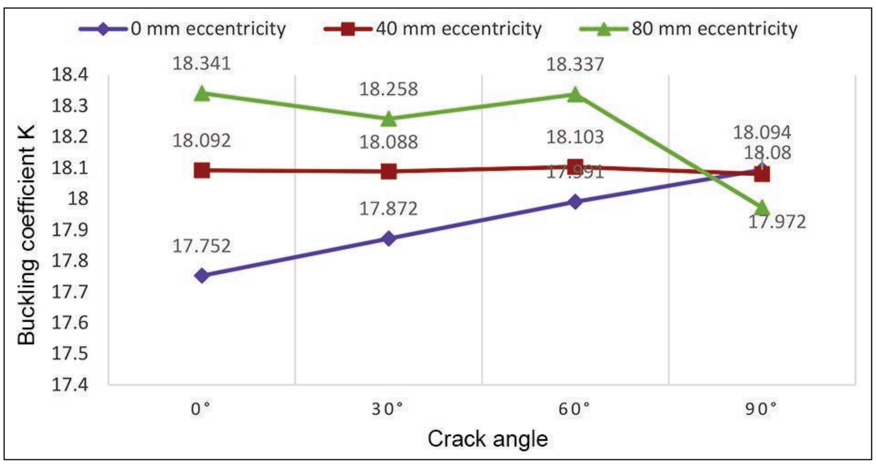

Fig. 4. Second buckling mode of SFSF stiffened plate for crack angle at different eccentricities

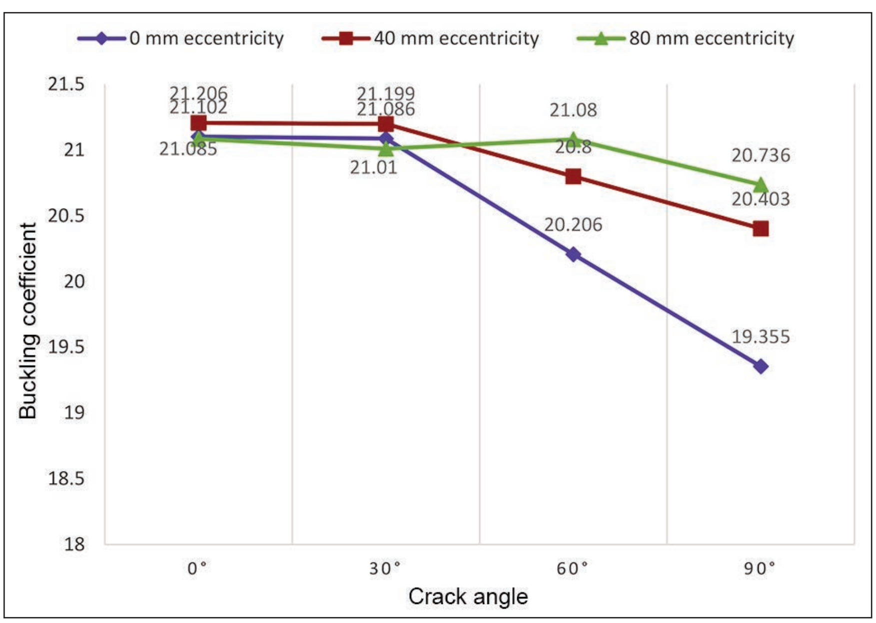

Fig. 5. Third buckling mode of SFSF stiffened plate for crack angle at different eccentricities

In this configuration, the crack acts as a stress concentrator along the primary load-bearing direction. The presence of the stiffeners, which are designed to support the plate against buckling, is compromised by a crack running alongside them. This essentially bypasses the stiffeners' reinforcing function, allowing the plate to buckle more easily. The crack effectively reduces the plate's effective width and its ability to resist in-plane compressive forces, leading to a substantial drop in the buckling coefficient. The eccentricity of e_y = 80 mm places the crack very close to the loading edge of the plate. Buckling often initiates near the unsupported or less constrained edges of a structure. By positioning the crack near the loading edge, the crack's weakening effect is amplified at the point where the compressive stress is highest, and the plate's resistance is weakest. This combination of a perpendicular crack and a location near the point of highest stress concentration creates a highly vulnerable area, causing the plate to lose stability and buckle at a much lower critical load.

Stiffened plate with CFCF edges

Figure 7 shows the first buckling coefficient modes of the stiffened plate when the crack is located at different eccentricities in CFCF plates. As shown in a stiffened plate with CFCF boundary conditions, the most critical buckling load happens in $\theta = 90°$ and e_y = 0. Also, it can be seen that in e_y = 80, the buckling load doesn't change with increasing the angle of the crack. Generally, it can be concluded that the most critical case occurs in $\theta = 90°$ and e_y = 0, and the least critical case occurs at e_y = 80 mm. Figures 8 and 9 show the second and third modes of buckling coefficients in stiffened plates with CFCF edges, respectively. In addition, the buckling mode

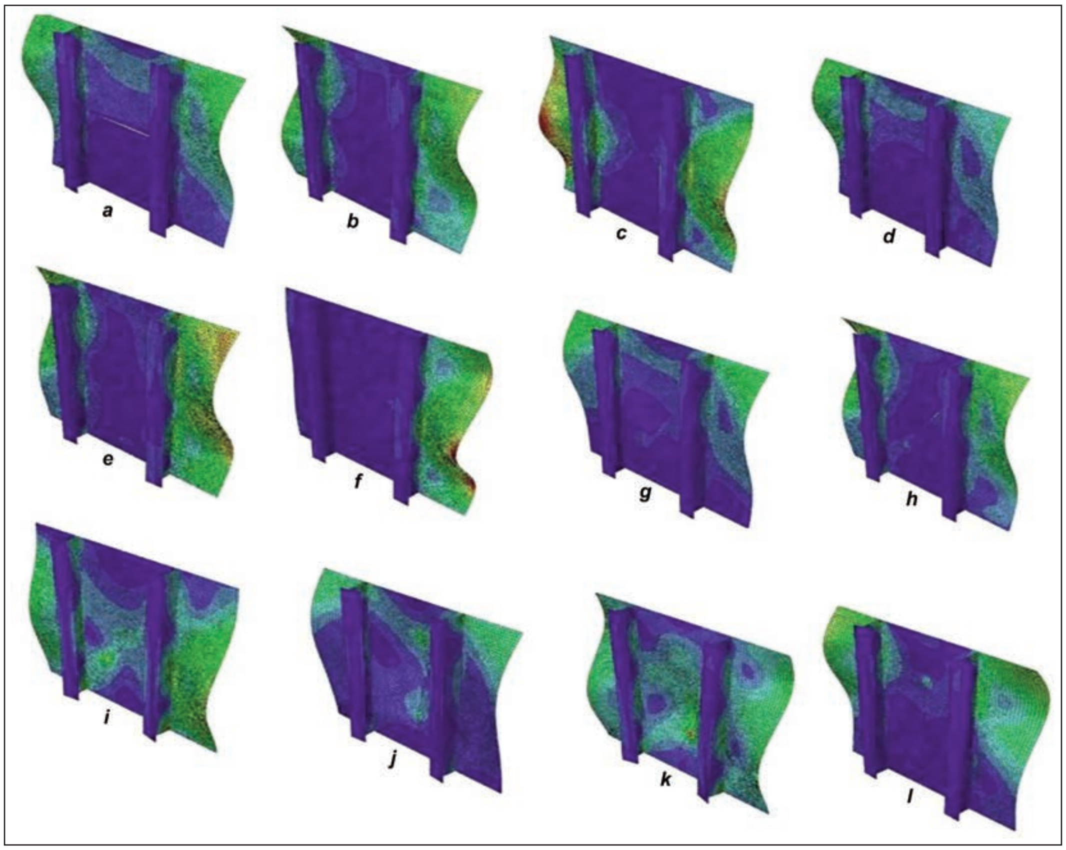

Fig. 6. Buckling mode shapes of SFSF stiffened plate with centric cracks at different angles: *a* – first buckling mode shape of a stiffened plate with a centric crack at θ = 0°; *b* – second buckling mode shape of a stiffened plate with a centric crack at θ = 0°; *c* – third buckling mode shape of a stiffened plate with a centric crack at θ = 0°; *d* – first buckling mode shape of a stiffened plate with a centric crack at θ = 30°; *e* – second buckling mode shape of a stiffened plate with a centric crack at θ = 30°; *f* – third buckling mode shape of a stiffened plate with a centric crack at θ = 30°; *g* – first buckling mode shape of a stiffened plate with a centric crack at θ = 60°; *h* – second buckling mode shape of a stiffened plate with a centric crack at θ = 60°; *i* – third buckling mode shape of a stiffened plate with a centric crack at θ = 60°; *j* – first buckling mode shape of a stiffened plate with a centric crack at θ = 90°; *k* – second buckling mode shape of a stiffened plate with a centric crack at θ = 90°; *l* – third buckling mode shape of a stiffened plate with a centric crack at θ = 90°

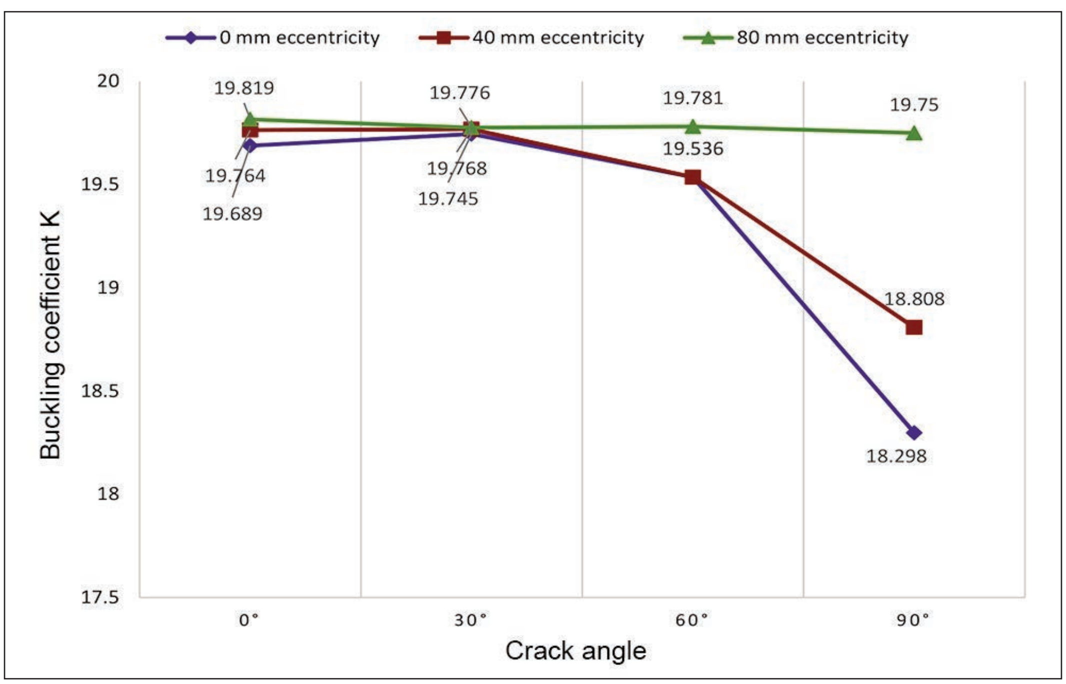

Fig. 7. First buckling mode of CFCF stiffened plate for crack angle at different eccentricities

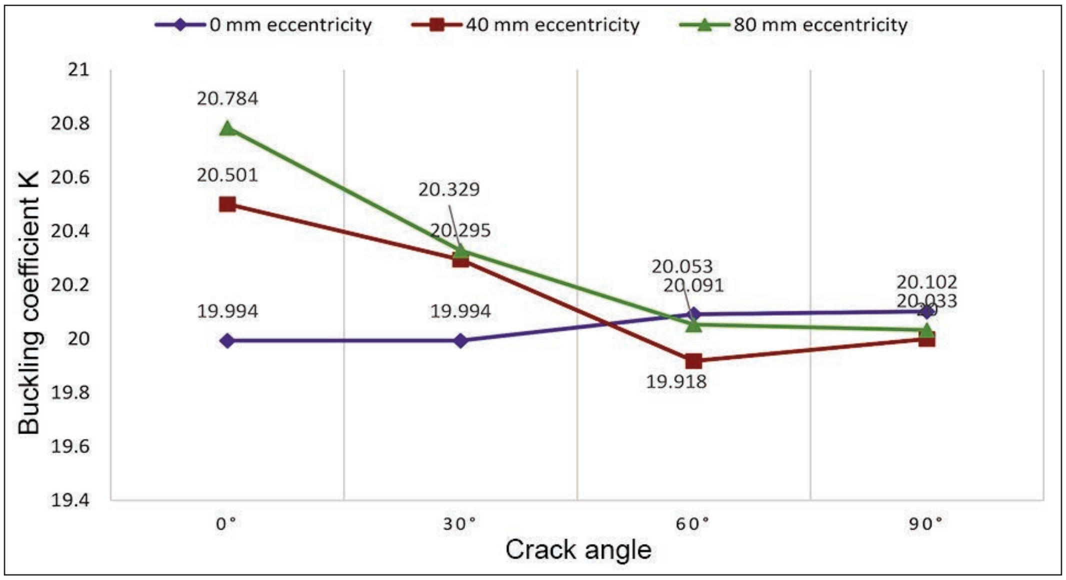

Fig. 8. Second buckling mode of CFCF stiffened plate concerning crack angle at different eccentricities

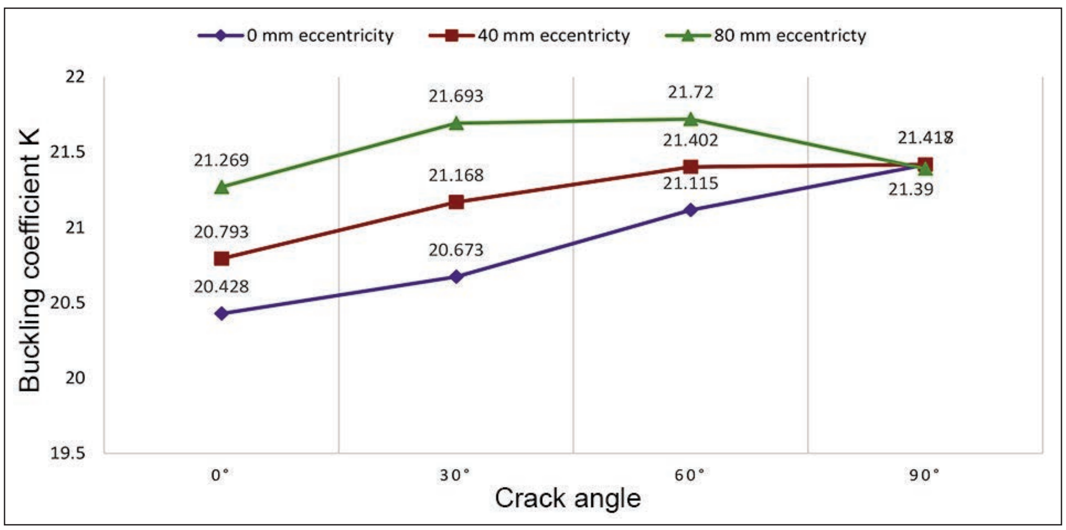

Fig. 9. Third buckling mode of CFCF stiffened plate for crack angle at different eccentricities

shapes of stiffened plates with centric cracks at different angles are shown in figure 10.

CONCLUSION

In this research study, the buckling behaviour of stiffened cracked plates made of Aluminium 1100 alloy under compressive loading was studied numerically by using Abaqus software. The following observation could be made on the findings of this work:

- The goal of the research was to achieve buckling loads and buckling coefficients of stiffened cracked plates in different cases. The effects of changing parameters such as the crack angle and its eccentricity, as well as the boundary conditions, were investigated.
- When the plates are reinforced by vertical or horizontal beams, their buckling stability increases; therefore, the effect of small cracks decreases and can be ignored. In the existence of a crack, as the crack angle increases from 0° to 90°, the buckling load decreases to the extent that in $\theta = 90°$ the most critical case occurs for both CFCF stiffened plates and SFSF stiffened plates.
- It was observed that as the crack becomes parallel with stiffeners, the buckling coefficient decreases. In stiffened cracked plates with SFSF boundary conditions, when the crack gets closer to the loading edge (e_y = 80 mm), the most critical case happens, whereas in CFCF stiffened cracked plates in e_y = 80 mm, the least critical case occurs.
- The presence of a crack significantly compromises the structural integrity of stiffened plates, as evidenced by a substantial reduction in their critical buckling load. In the most critical scenario, where the crack's orientation and location are least favourable buckling strength is reduced by approximately 11% for Clamped-Free-Clamped-Free (CFCF) stiffened plates and a more severe 17% for Simply Supported-Free-Simply Supported-Free (SFSF) plates.

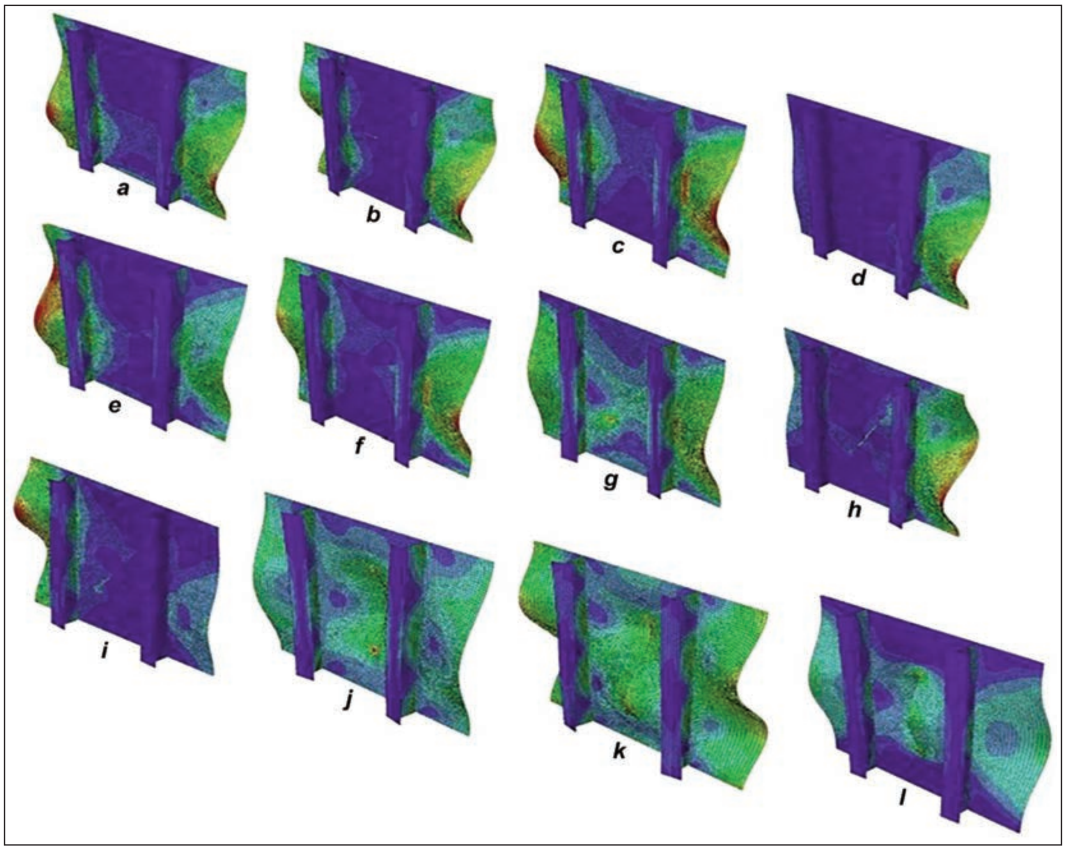

Fig. 10. Buckling mode shapes of CFCF stiffened plate with a centric crack at different angles: *a* – first buckling mode shape of a stiffened plate with a centric crack at θ = 0°; *b* – second buckling mode shape of a stiffened plate with a centric crack at θ = 0°; *c* – third buckling mode shape of a stiffened plate with a centric crack at θ = 0°; *d* – first buckling mode shape of a stiffened plate with a centric crack at θ = 30°; *e* – second buckling mode shape of a stiffened plate with a centric crack at θ = 30°; *f* – third buckling mode shape of a stiffened plate with a centric crack at θ = 30°; *g* – first buckling mode shape of a stiffened plate with a centric crack at θ = 60°; *h* – second buckling mode shape of a stiffened plate with a centric crack at θ = 60°; *i* – third buckling mode shape of a stiffened plate with a centric crack at θ = 60°; *j* – first buckling mode shape of a stiffened plate with a centric crack at θ = 90°; *k* – second buckling mode shape of a stiffened plate with a centric crack at θ = 90°; *l* – third buckling mode shape of a stiffened plate with a centric crack at θ = 90°

- This quantifies the vulnerability introduced by even a small crack and highlights that the plate's boundary conditions play a crucial role in determining the extent of the stability loss. The greater reduction in SFSF plates suggests they are more susceptible to this specific type of localised damage.
- The results are directly applicable to the design and maintenance of marine vessels and offshore platforms. The data on how crack orientation and location reduce buckling stability helps naval architects and engineers make more informed decisions when designing Aluminium stiffened plates for ship hulls, bulkheads, and other structural components.
- The research on stiffened plates can be applied to structural integrity assessments of heavy machinery and large flat processing components used in the textile industry.
- This study is limited to numerical analysis, lacking experimental validation for its findings. Future research should involve physical experiments to confirm the buckling behaviour of cracked stiffened plates under various loads. Additionally, extending the analysis to include fatigue crack growth and the effects of corrosive environments would provide a more comprehensive understanding for marine and textile applications.

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