Fabrication and Testing of Novel Aluminium Composite Panel and Analysis of Composite Panel for Impact Loads in Collision Environment for Four-Wheelers Automobile

Valluru Nagendra babu, G Ramakrishna

Abstract*: Impact loads from the crash of automobile always challenge the structural parts of the collided vehicles. Modern high – speed vehicles are subjected to high impact loads during accidents when the vehicle is accelerating at high speeds. This results in structural damage to the vehicle as well as passengers in the vehicle. In recent years, high-strength aluminum alloys have increasingly been used for building high-speed vehicles, and other types of weight-critical structures. In such structures, stiffened panels are the basic strength members. Composite panels can be used for the car body to reduce the weight of the vehicle and to increase the collision resistance. In this study, the aluminum composite panels with composite filled stiffeners are fabricated and tested experimentally under compression and impact loadings. Recycled ceramic powder, recycled steel flakes, and E - glass fiber mesh is taken as reinforcements and thermoplastic resins as matrix materials in the preparation stiffener filler composite. The composite panel specimens are fabricated and are tested experimentally under axial compression for collapse resistance.

Keywords: *Composite panel, collision test, compression, stiffened cores*

I. INTRODUCTION

In modern days stiffened panels are used widely as one of the engineering structures. These play a major role in civil engineering basic components, and aerospace structures and marine structures. The simplicity in the design and manufacturing of those structures, their economic feasibility and their effectiveness in resisting compression loads and lateral loads make them utilize in various engineering applications.

The behavior of these panels under various types of loading is dependent on the process followed in their manufacturing and the respective applications. When the plate and stiffeners (beams with appropriate sections) are assembled by means of welding process plate stiffeners are formed [1]. In recent years the usage of composite panels for structural applications became a major interest due to the good strength to weight characteristics. While designing the structure and during the assessment of safety for the structure, collapse strength calculation is the critical part [2].

Axial compression is the major type of loading faced by these stiffened panels. As a result, the failure of these stiffened panels will be due to collapse modes. These failure modes are mainly classified into six and are:

1. Mode I: Overall buckling followed by overall collapse
2. Mode II: Skins collapse between stiffeners without stiffeners failure, which occurs due to biaxial compression force.
3. Mode III: Collapse of skin-induced or stiffener induced failure of stiffeners together with attached skins.
4. Mode IV: Stiffener buckling
5. Mode V: Flexural - torsional buckling or stiffeners tripping.
6. Mode VI: Massive yielding.

At the least values of the ultimate loads evaluated at six modes for these stiffeners collapse.

For predicting the stiffened panels' ultimate strength, many theoretical models and numerical models have been established [3]. The research in the field of stiffened panels especially in the case of aluminum stiffened panels is limited only to the marine and aviation vehicles only [4]. In the field of automobiles, the usage of these panels is at an immature level only. This study aims at developing aluminum stiffened panels reinforced with recycled ceramic particle composites, E-glass fiber mesh composites and recycled steel flake composites in the stiffener sections. Experimental evaluations are carryout to find the collapse modes of the proposed models. The experimental results obtained are validated with the formulations by Collette [6] and Kee et al. [7]

II. MODELING AND FABRICATION OF TEST SPECIMENS

The aluminum stiffened panel structures used for marine and aviation applications is shown in Figure 1. It comprises of sheet metallic plates and support members. The nomenclature used for the composite stiffened panel structure is shown in Figure 2.

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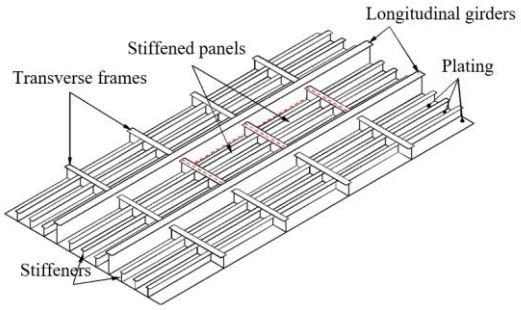

Fig. 1: Stiffened panel

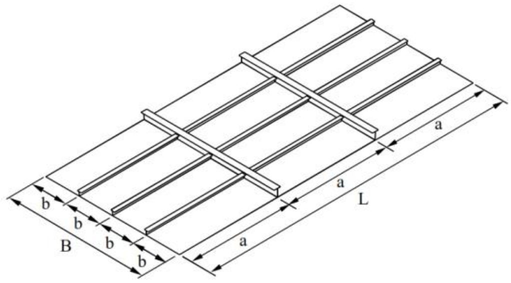

Fig. 2: Nomenclature

Where B = panel width
b = longitudinal spacing of stiffeners
a = transverse spacing of stiffeners
L = length of panel

Solidworks is used to design the models. Stiffeners are welded to the aluminum skin. Thermoplastic epoxies are used as matrix material and recycled ceramic powder, metal flakes, and E – glass fibers are used as reinforcement materials in this study. Table 1 represents the materials of the considered prototypes in this study.

Table 1

ID	Plates	Stiffeners	Stiffeners Reinforcement
1	Al	Al	NA
2	Al	Al	Recycled ceramic
3	Al	Al	Recycled ceramic
4	Al	Al	Recycled steel
5	Al	Al	Recycled steel
6	Al	Al	E-glass fiber
7	Al	Al	E-glass fiber

The characteristics of the reinforcement materials and the matrix materials considered in this study are represented in Table 2.

Table 2

ID	Reinforcement	Reinforcement %	Reinforcement Type
1	NA	NA	NA
2	Recycled ceramic	30	Powder
3	Recycled ceramic	40	Powder
4	Recycled steel	30	Flakes
5	Recycled steel	40	Flakes
6	E-glass fiber	30	Mesh
7	E-glass fiber	40	Mesh

Figure 3 shows the image of the prepared composite panel with ID 2 configuration.

Fig. 3: ID 2 Composite panel

III. EMPIRICAL CORRELATION

For the aluminum stiffened panels ultimate limit strength (ULS) closed-form proposed by [8]. The imperfection parameters at various levels for the models and their reliability analysis are estimated by following empirical correlations:

1) Plate slenderness ratio:

$$\beta = \frac{b}{t}\sqrt{\frac{\sigma_{\mathrm{Yp}}}{E}}$$

2) Column slenderness ratio:

$$\lambda = \frac{a}{\pi r}\sqrt{\frac{\sigma_{\mathrm{Yeq}}}{E}}$$

3) Radius of gyration:

$$r = \sqrt{\frac{I}{A}}$$

4) Maximum plating initial distortion amplitude:

$$w_{opl} = \begin{cases} 0.018\beta^2 t & \text{for slight level} \\ 0.096\beta^2 t & \text{for average level} \\ 0.252\beta^2 t & \text{for severe level} \end{cases}$$

5) Half-wave plating initial distortion amplitude:

$$w_{o1} = \begin{cases} 0.0059\beta^2 t & \text{for slight level} \\ 0.093\beta^2 t & \text{for average level} \\ 0.252\beta^2 t & \text{for severe level} \end{cases}$$

6) Localized initial mode distortion amplitude:

$$w_{ob} = \begin{cases} 0.00033\beta^2 t \approx 0.0 & \text{for slight level} \\ 0.0101\beta^2 t & \text{for average level} \\ 0.0365\beta^2 t & \text{for severe level} \end{cases}$$

7) Buckling initial mode plating distortion amplitude:

$$w_{om} = \begin{cases} 0.0 & \text{for slight level} \\ 0.00552\beta^2 t & \text{for average level} \\ 0.0468\beta^2 t & \text{for severe level} \end{cases}$$

8) Maximum initial column distortion amplitude:

$$w_{oc} = \begin{cases} 0.00016a & \text{for slight level} \\ 0.0018a & \text{for average level} \\ 0.0056a & \text{for severe level} \end{cases}$$

9) Half-wave column initial distortion amplitude:

$$w_{ol}^{c} = \begin{cases} 0.0 & \text{for slight level} \\ 0.00155a & \text{for average level} \\ 0.00525a & \text{for severe level} \end{cases}$$

10) Maximum initial sideways stiffeners distortion amplitude:

$$w_{os} = \begin{cases} 0.00019a & \text{for slight level} \\ 0.001a & \text{for average level} \\ 0.0024a & \text{for severe level} \end{cases}$$

11) Half-wave sideways stiffeners initial distortion amplitude:

$$w_{ol}^{s} = \begin{cases} 0.0 & \text{for slight level} \\ 0.000574a & \text{for average level} \\ 0.0018a & \text{for severe level} \end{cases}$$

IV. TESTING

The fabricated stiffeners are tested on the axial compression testing machine by taking simply supported conditions on both sides of the composite plate stiffeners. To obtain the simply supported condition, steel rods are inserted on both sides of the composite stiffened plate. Supporting jigs are used to support the ends from slipping. Totally, seven prototype structures indicated in table 1 are tested.

Fig. 4: Collapse testing of composite panels

Figure 4 represents the experimental setup. The instrumentation used in the experimentation is listed in Table 3.

Table 3

Instrument	Test
Jigs	Fix the panels
Strain gauges	Measure deflection
Load cells	Measure applied loads
Rollers	End supports
Piezo accelerometer	Vibration measurement

V. RESULTS

The collapse testing on the proposed composite panels was conducted on the axial compression machine. For proposed composite panels ultimate strength was calculated from the ultimate load values obtained from load vs displacement graphs. Figure 5 shows the plot for load vs displacement for all the seven models, from ID 1 to ID 7 considered in this study. Table 4 shows the ultimate load and the respective displacement values.

Table 4

ID	Ultimate Load (P_U) (kN)	Displacement (mm)
1	804.41	10.9
2	918.94	11.1
3	934.76	11.2
4	1345.42	14.1
5	1531.57	10.4
6	832.44	11.1
7	872.71	11.8

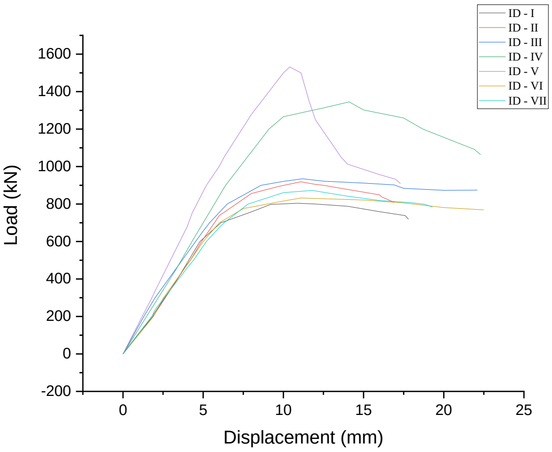

Fig. 5: Load vs displacement comparison plot

Equivalent yield stress, slenderness ratio for plate and stiffeners are evaluated by using equations from (1) through (3) and are represented in Table 5.

Table 5

ID	P_U (kN)	σ_U (MPA)	σ_{U}/σ_{Yequ}	β	λ
1	804.41	97.61	0.421	3.87	0.839
2	918.94	113.41	0.532	3.87	1.054
3	934.76	112.08	0.519	3.87	1.045
4	1345.42	132.04	0.564	3.87	1.040
5	1531.57	132.34	0.653	3.87	1.016
6	832.44	97.99	0.472	3.87	1.064
7	872.71	111.59	0.519	3.87	1.063

Where P_U = Ultimate load
σ_U = Ultimate compression strength
σ_{Yequ} = Equivalent yield stress
β = Plate slenderness

ratio

λ = Column slenderness ratio

The distorted amplitude for the plating and stiffener obtained numerically and experimentally are tabulated in Table 6. In Table 7 the collapse modes for the seven proposed composite stiffener panels are tabulated.

Table 6

Case	Numerical distorted amplitude		Experimental distorted amplitude	
	Plating	Column	Plating	Column
Maximum initial distortion amplitude	7.54	2.68	7.83	2.95
Half-wave initial distortion amplitude	6.45	2.52	6.13	2.39
Localized initial mode distortion amplitude	1.09	NA	1.18	NA
Buckling initial mode plating distortion amplitude	1.40	NA	1.74	NA
Maximum initial sideways stiffeners distortion amplitude	1.152		1.127	
Half-wave sideways stiffeners initial distortion amplitude	0.864		0.947	

Table 7

ID	Collapse Mode	Remarks
1	III+IV	The collapse of skin-induced or stiffener induced failure of stiffeners together with attached skins + Stiffener buckling
2	III	The collapse of skin-induced or stiffener induced failure of stiffeners together with attached skins
3	III	The collapse of skin-induced or stiffener induced failure of stiffeners together with attached skins
4	IV+V	Stiffener buckling
5	V	Flexural - torsional buckling or stiffeners tripping
6	III+IV	Stiffener buckling
7	III+IV	Stiffener buckling

VI. CONCLUSION

This study aims at developing aluminum stiffened panels reinforced with recycled ceramic particle composites, E-glass fiber mesh composites and recycled steel flake composites in the stiffener sections. Experimental evaluations are carryout to find the collapse modes of the proposed models. The results showed that ID4 collapse at the ultimate load of 1531.57 KN and at ultimate stress of 132.34 KN which has the maximum sustainable capability among the 8 models considered in this study. Whereas the stiffened panel with no composite filler, ID1 collapse at the ultimate load of 804.41 KN and at ultimate stress of 97.61 KN which has the minimum sustainable capability. As a result of introducing the composite filler, the ultimate load-bearing capacity was of the ID4 model was enhanced compared to that of ID1.

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