DESIGN OF OPTIMISED PIC BEAM WITH K-NN CLASSIFICATION

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In the present study, design optimisation of PIC beam undergoing bending was carried out with the help of K-NN classification based on the triaxiality which is able to suggest dominant loading types in regions, i.e. tensile, compressive or shear. After K-NN classification, beam regions are divided into three parts, i.e., tension dominant, compression dominant and shear dominant. Composites are stacked for each region by robust sequences, which was investigated by previous study. The optimised PIC beam showed excellent load resisting capability as well as energy absorption during three-point bending.

Index Terms - Composite beam, K-NN classification, piecewisely-integrated composite (PIC), triaxiality.

I. INTRODUCTION

Nowadays, material strengthening and lightweight structure of vehicles are prevalent to answer for the enhancement of regulation as well as safety of passengers in the automotive industries [1]. One of the best ways to improve safety without sacrificing weight saving effect is usage of composites since they have higher specific strength and specific stiffness [2]. Composite structures have normally monotone stacking sequences in an entire body, therefore, they show over-design or under-design simultaneously depending upon the location of a structure, which makes composites difficult to be applied to heavy-loading structures. Of particular interest to this study is suggesting a novel concept of designing compositebeams to promote the lightweight effect and crashworthiness simultaneously. Cheon et al [3,4] suggested a novel type hybrid composite bumper beam for passenger cars and performed FE analysis. Hosseinzadeh et al [5] carried out parametric studies for designing composite beams against low velocity impact. Davoodi et al. [6,7] measured mechanical properties of bio-composite and concept design of passenger car bumper beams.Belingardi et al. [8] optimized pultruded composite beam profile by numerical simulation.Kim et al. [9] also optimised automotive hybrid composite bumper beam.As far as concerned, previous researches normally showed the monotone stacking sequence to entire body of composite beam without changing. The aim of the current work is to suggest a piecewisely-integrated composite (PIC)beam, which is optimisedfor bending type loading. Bending is one of frequent external loadings in mechanical structures. When a beam is exposed to bending, tension, compression and shear stresses are generated in entire regionof the beam.In the meantime, robust stacking sequences against tension, compression and shear have been suggested by previous study, i.e., robust stacking sequence against tension is $[\,90/\,0/\,\bar{0}]_{6s}$, $[\,\pm 5 / \pm 45 / 90\,]_{3s}$for compression and $[\,0/90]_{15T}$ for shear [4,10].Next is to find the dominant loading type along with location in the beam, therefore, reference points are included in finite element modeling of beam. Triaxiality is evaluated and categorises the loading type at each reference point. The triaxiality is defined by Eqns (1)-(3).

$$\eta = \frac{\sigma_m}{\bar{\sigma}} \tag{1}$$

where,

$$\sigma_m = \frac{1}{3}(\sigma_1 + \sigma_2 + \sigma_3) \tag{2}$$

and

$$\bar{\sigma} = \sqrt{\frac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]} \tag{3}$$

Reference points is not able to define loading type of all elements in the beam, therefore, K-NN (Nearest neighbours) classification, which is applied to machine learning,is used to assign loading type of elements near reference points with K-number of reference points[11,12].

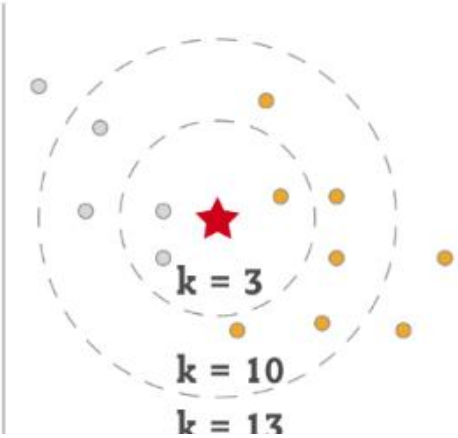


Fig. 1. Schematic diagram of K-NN classification [13].

Once the dominant loading type for every element in the beam is assigned, then new FE modeling with proper corresponding stacking sequences of

composites depending upon the dominant loading type, i.e. PIC beam, is carried out. The result is compared with three cases of monotone stacking sequence composite beam.

II. MODELING AND SIMULATION WITH K-NN CLASSIFICATION

A. K-NN classification

As mentioned above, K-NN classification is used to assign a dominant loading type to the undefined region with nearest K-number of reference points. To assign a dominant loading type, gathering nearest reference points are necessary, according to the values of two parameters, i.e., distance between the unassigned region and the reference point as well as K value. Four representative options are existing to calculate distance, i.e., Euclidean, Manhattan, Mahalanobis and Minkowski, and Euclidean distance which is known to be the spatially shortest distance, is chosen in the present study.

As far as K value, smaller value reflects local effects, therefore, noise becomes bigger. On the other hand, bigger value over-nomalises with ambiguous borders between characterised data region [11]. In the present study, preliminary analyses were conducted along with K-NN types.Also, their resultsprovided us with proper value of 10 for K based on the accuracy, which is shown in Table 1.

Table 1 Accuracy of each K-NN type

K-NN type	K value	Distance	Accuracy
Medium	10	Euclidean	87.5%
Coarse	100	Euclidean	77.5%
Cosine	10	Cosine	77.5%
Cubic	10	Minkowski	87.5%
Weighted	10	Euclidean	93.8%

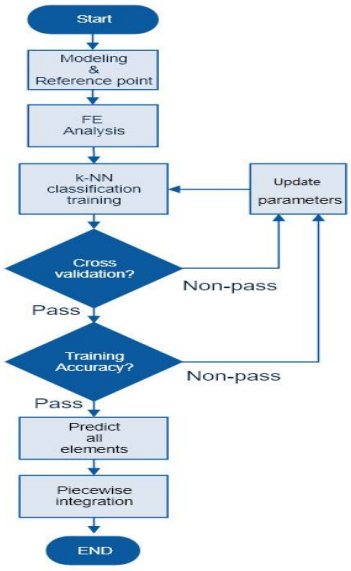


Fig. 2. A flowchart for K-NN classification.

Reference points are assigned to obtain data of triaxiality by FE analysis. Triaxiality data is dividing a loading condition of elements into three classes, i.e., tension, compression or shear. Next, K-NN classifies, current step is called as training, reference points based on the triaxiality data by themselves, which is followed by accuracy checks as well as validation [12]. Each iteration requires update parameters, i.e., distance, weighting factors as well as K-value. When the validation and the accuracy fulfill the criteria, then assign the classes into all elements. Finally, the piecewisely-integrated composite beam model is achieved. Fig. 2. summarises all the steps by flowchart.

B. Finite elements and analysis

Preliminarily three-point bending FE analysis of an aluminium alloy beam was performed. Fig. 3 illustrates FE model of three-point bending analysis. LS-DYNA (Livermore software technology co.), one of representative commercial FE software, was used for FE analysis. Preliminarily three-point bending FE analysis of an aluminium alloy beam was performed. Fig. 3 illustrates FE model of three-point bending analysis. LS-DYNA (Livermore software technology co.), one of representative commercial FE software, was used for FE analysis. Crosshead speed was set to be 10 mm/min.

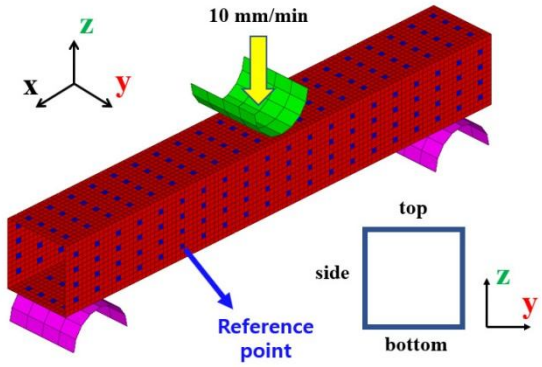


Fig. 3. Configuration of three-point bending FE model.

Depending upon the triaxiality value of finite element, tension dominant when the triaxiality is bigger than 0.1, compression dominant in case of lower triaxiality than -0.1, and shear dominant when triaxiality lies between -0.1 and 0.1 as summarised in Table 2 [14].

Table 2Triaxiality vs. dominant loading characteristics

Triaxiality (η) condition	Dominant loading
$\eta > 0.1$	Tension
$\eta < -0.1$	Compression
$-0.1 < \eta < 0.1$	Shear

Reference points Preliminarily three-point bending FE analysis of an aluminium alloy beam was performed. Fig. 3 illustrates FE model of three-point bending analysis. LS-DYNA (Livermore software technology co.), one of representative commercial FE software, was used for FE analysis. 100 number of reference points were seeded for bottom, top and side,

respectively as shown in Fig. 3. Principal component analysis was applied to improve accuracy with weighted square inverse type K-NN along with value 10 for K as well as Euclidean distance [15,16].

III. RESULTS AND DISCUSSION

Accuracies for bottom, top and side surfaces were found to be reasonable values, 96.3%, 82.5% and 70%, respectively. As mentioned above, tension dominant region was modeled with stacking sequence of $[\,90/\,0/\,\bar{0}]_{6s}$, for compression dominantregion, $[\,\pm 5\,/\,\pm 45\,/\,90\,]_{3s}$, and shear dominant regionwas stacked by $[\,0/90]_{15T}$. Fig. 4 shows the optimisedPIC beam associated with K-NN classification.

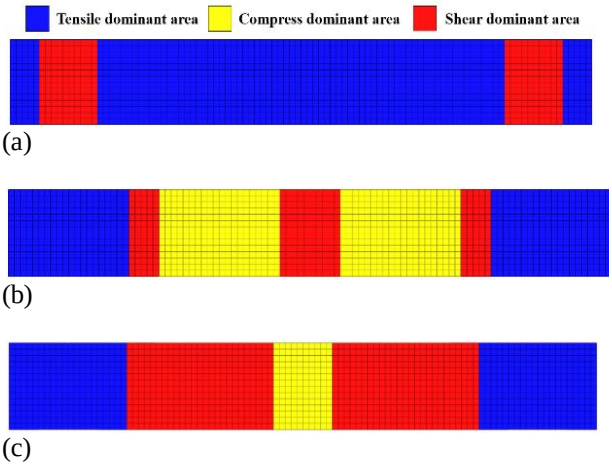


Fig. 4. Optimised PIC beam: (a) Bottom view, (b) top view, and (c) side view.

Also, three-point bending analyses were carried out for PIC beam as well as three additional cases of composite beams with conventional monotone stacking sequences, i.e., case 1 is $[\,90/\,0/\,\bar{0}]_{6s}$ only, case 2 is $[\,\pm 5\,/\,\pm 45\,/\,90\,]_{3s}$ only and case 3 ismonotone $[\,0/90]_{15T}$.
Fig. 5 shows the comparison of three-point bending analysis results.

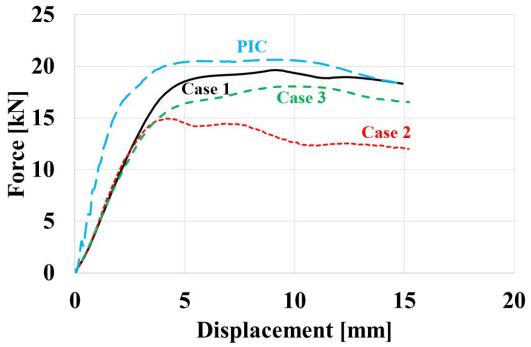


Fig. 5. Force-displacement curves of each case.

As shown in Fig. 5, the optimisedPIC beam showed highest external load resisting capability compared to other types of monotonic stacking-sequenced composite beams.

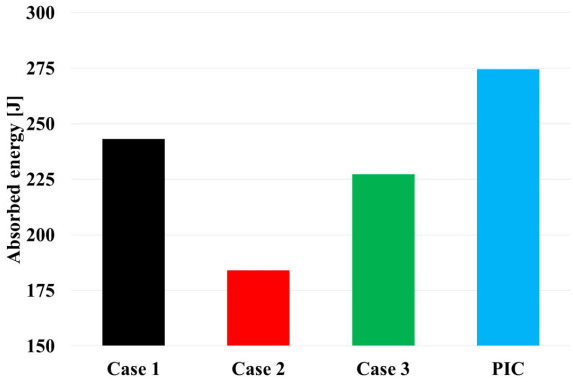


Fig. 6. Comparison of energy absorption for each case.

Energy absorption for each case of composite beams were plotted in Fig. 6. As shown in Fig.6, PIC beam showed most excellent characteristics among them. From Figs. 5 and 6, it was found that the PIC shows 5% higher load resisting capability than that of case 1, and 15% bigger energy absorption than that of case 1, therefore, it was revealed that the PIC beam is competitive compared with composite beam with monotone stacking sequences.

CONCLUSION

An optimiseddesign of PIC beam was proposed with the help of the K-NN classification as well as triaxiality to investigate the loading status of each region. Three-point bending analyses were carried out for PIC beam including conventional monotone stacking sequenced composite beams. The PIC beam showed superior characteristics both for load resisting capability and energy absorption, therefore, it was revealed that the PIC beam is competitive compared with composite beam with monotone stacking sequences.

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