Crash Energy Absorption of Vehicles Using Structural Configuration Methods

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Abstract- *The primary factor considered in terms of domestic, passenger, and social vehicles in terms of design and development aspects, including their qualifications amongst the commuting modular vehicles along roads, various studies revealing that over 1.3 million commuters die in road accidents each year, frontal collisions being proven to be the major cause, and exclusive evaluations being done on vehicular crashworthiness and seater safety. The F E A procedures ensured here are for analysing various E A configurations being modelled and designed, thus analysed through F E A using a suitable FEA software workbench, and thus considered E A structures are rounded tube, tube, and hybrid sections whose functionality is evaluated on various crashworthiness assessment factors. The present work aims to gain a thorough understanding of the impact of combined sectional textures along plastic deformability modes, CF, and EA characters, as well as to ensure that rounded tube in tube and inversion tube designs are dominant, efficient, and capable of practical EA functionalities such as sophisticated crash functionality.*

Keywords: *energy absorption, impact decelerations, crush force behaviour, plastic deformation, numerical methods and ABAQUS®.*

I. INTRODUCTION

The concept of automobiles and automobile vehicles being introduced between 20th century, thus brought an extravagant impact on the continually advancing world comparing to any other concepts and technologies thus being introduced to the real world, predominantly recognizing on a most significant dependable modes of transportation, these automobile vehicles brought a redundant modification along the normal man's lifestyles globally, by becoming a major depending part of one's life. As there is being a consistent and progressive advancements in the technological aspects of engineering fields , the automobiles being most relevant and affordable for several millions of needy by reaching with variant cost factors across the globe, also the advances along the society being much influential in an increased dependency on the automobiles with varied speeds, thus creating a societal threat along the human safety thus leading towards accidents with higher (unexpected collisions in variant unexpected forms) depending on the varied moods of the driving persons sometimes and also due to various circumstances, thus these road accidents being categorised as in the below figure 1

Initial classical inventive layout of frontal collapsible E A shape [1] explored as unique fashion inside the layouts along facial systems. Comprehensive studies along vehicular collisions, crashworthiness including seaters bio-mechanics, through longer years, brought about the evoking of numerous harm scenarios like head harming/collisions (HIC) [2],[3] Brain-Injury-Criterion (BrIC) [4],[5] Neck Damage Criterion (NIC) [6] and chest compression tiers, and many others, such critical issues being explored as a cause of acceleration/decelerations, thus influenced in an collective observations and assessment of harming stages for specific bombarding situations and to reach at the restricting entities of decelerations (intruded into equal weigh down forces) and forces [7] a human body thus sustains any harm apart of critical harms. Several previous times, thus, being widespread engineering practice with all the automobile producers to layout the frontal EA systems against overwhelm forces being inside such permissible magnitudes towards satisfying with legal protection policies.

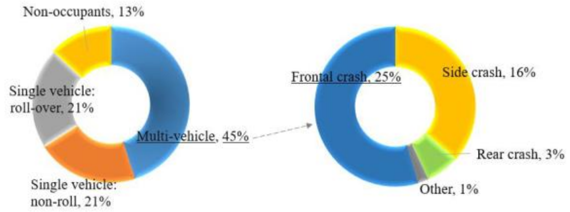


***Fig 1**. Mortality Distribution along accident types.*

II. LITERATURE REVIEW

Crashworthiness, including seater's protection being attained a pinnacle preference in motors through the advent of Highway-Safety-Act within the 2nd part of twentieth century with the aid of the United States Government. This regulation caused the empanelment of recommendations along vehicle productions across variant factors of the car for seaters protection. These protection governances further enforced as Federal-Motor-Vehicle-Safety Standards (FMVSS) in U S A and shortly the opposite nations also commenced empowering similar requirements and pointers, as suitable to their localities. Vehicle protection structures are modelled to guard the commuters in the course of numerous collision eventualities related to frontside collision, aspect blow, roll-over crashes or another scenario. Every such scenario arises in numerous ways and every scenario being peculiar in its own-format through distinctive feature against cause to vehicle including depth of accidents to its seaters [8],[9] Crashworthiness as regarded to commonplace frontside crash effect thus be concentrated as a measurand in vehicle's frontside Energy Accumulation (EA) shape sustainability to take in the effect power by way of permitting the restrictive plastically deformative whilst owning sufficient power to keep away from infusions against engine-sets along seaters mobile and to hold the effect prompted deceleration ranges in the humane tolerable limits (weigh down forces have to be in the permissible limits) [10].

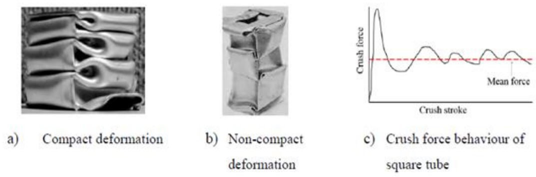
A. Crashworthiness meaning

'Crashworthiness' was initially adapted in aviation sectors as a measurand in evaluating a structures capability to safeguard their inhabitant in sustaining every harm thru crashes. Along automotive perspectives' connecting to vehicular structural vicinities ensuring plastically deformability along front sides, towards consistency along seater's space against collisions thus come-across a considerable deceleration. Fewer the harm/damages to the vehicular cross sections including the seater post colliding, elevated in crashworthiness thru vehicle nor optimal the performance [9]

***Fig 2**. (a) When a car collides with an elastically loaded spring, it is slowed by the compressive spring, (b) It is subsequently accelerated by reversing the spring [11]*

B. Tubes with Multi-Cornered Sections

Tubes of cross-sections comprising a diverse variety of corners were examined for power soaking up applications within the beyond. Simple rectangular tubes were widely researched in this family, with an obsessive focus on deformation behavior and weigh down pressure behavioral patterns.



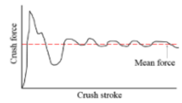


***Fig 3.** A conventional tube splitting procedure and its observed behaviour of crush force*

C. *Tubes made of composite materials*

Composite materials have recently demonstrated a strong desire for power-absorbing functionalities. If the cloth residences in phrases of harm initiation and evolution are tuned well in all of the 3 fundamental locations. Composite materials with a tendency to deform and fail steadily may be the ideal options for power absorption applications. So far, carbon-fiber and glass-fiber composites have been extensively researched for automotive applications.[12]

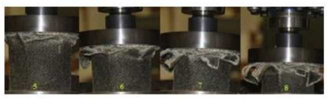


***Fig 4.** (a) Progressive deformation mode and (b) A typical composite material's crush force behavior*

D. Configurations with multiple cells

Multi-celled arrangements often possess a near-best weigh down pressure behavior with fluctuations in an entirely slender band after the initial height. But it is proven that a major drawback of such configurations is the stroke performance with a premature or late increasing density of the cloth of the overwhelmed element with a tradeoff within the vital need of absorption of power. There are a few empirical formulae applicable for predicting weigh down pressure that can be depicted in terms of square aspect, tube thickness, number of cells, and cloth float tension. [13] , [14]

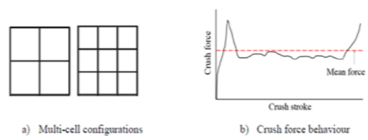


Fig 5. *Typical multi-cell design's cross-sections and crush force behaviour [15]*

E. Research Methodology

The prime objective of the concurrent work is to achieve structural configurations that exhibit plastic deformation sample with managed preliminary top crush forces, uniform crush forces at some stage in the crush forces stroke, better crush forces and stroke efficiencies for eloping the quantity of power accumulated.

(a) Plastic deformability of E A models till now being examined and noticed for any further aspects to be considered for the using the gathered literatures focussing on specific factors like crushing forces characterisation, deformability models, and collective E A along advances in materials. (b) Finite element analysis (F E A) methods being broadly employed thru numerous designs, ideas along E A models, validating perfections along FEA techniques, fewer trials being noticed along gathered literature empowers along generalised FEA coded ABAQUS, including findings along simulation being matched against practical values thus obtained. (c) Numerous modular designs being generalised, also being assessed along common crashworthiness factorials thru F E A techniques, tubular inversions including plastic deformability being predominant along E A being chosen for current project work. (d) Collective F E A simulations being executed along deigning tubular sectional models thus being validated practically in quasi-static vicinity. (e) Towards enhancing SEA factorials fewer multi-variant-mixtures being adapted along foams as a novel approach, thus assessed along generalised crashworthiness elements through FEA techniques.

III. F E A AND EXPERIMENTAL VALIDATION

EA systems with distinct geometrical pass sections, made of aluminium and alloying elements from various literatures, for which experimental results are required, are modelled and numerically simulated using the cost-effective FEA code ABAQUS [16].

A. Experiment Validation and FEA Simulation of EA Specimen-1

These experimental observations were thus recorded on a square cross section specimen with dimensions of 200 x 75 x 75 mm and a thickness of 1.3 mm, as shown in Figure 6. This EA shape is manufactured from AA6061-O grade with young's modulus = 69 GPa, Poisson's ratio = 0.3, yield strength = 71 MPa and density = 2580 kg/m3. In the experimental setup [17], the specimen's lowest face became a rigid block. A rigid block connected to the machine's loading head was used to affect the specimen on the upper end at a constant axial speed of one mm/s, as shown in Figure 6. In ABAQUS/Explicit 6.14-3, the EA shape is discretized using first order shell elements (S4R). The top and bottom plates are modelled as rigid elements (R3D4).

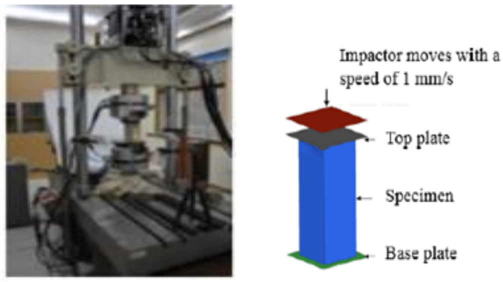


Fig 6. *EA specimen-1 Experimental and FEA Setups*

Following a convergence study, the detail length is set at 1.4 mm, a size that is sufficient to capture plastic deformation as well as self-touch effects.

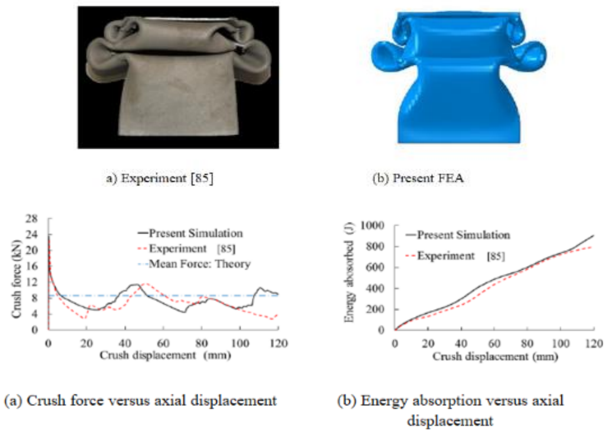


Fig 7. *Crush force and energy absorption characteristics of EA specimen 1*

Table 1 shows a comparison of this common EA structure-1 with the current FEA, experiment, and principle based, entirely on crashworthiness overall performance parameters.

Table 1. *EA specimen crashworthiness performance 1- compares simulation to experiment*

Parameter	Mass (kg)	Peak force (kN)	Mean force (kN)	TEA (kJ)	Crush stroke (mm)	CFE (%)	SE (%)	SEA (kJ/kg)
Present simulation	0.2	23.6	7.5	0.9	120	31.8	60.0	4.5
Experiment [85]	0.2	22.5	6.8	0.8	120	30.2	60.0	4.0
Theory [86]	0.2	-	8.6	1.0	120	-	-	5.2
% Difference in present simulation w.r.t. [85]	0	4.9	10.3	12.5	0	5.3	0	12.5

B. Experiment Validation and FEA Simulation of EA Specimen-2

In this observation, EA specimen-2 of a variant celled (4 cell) column is used for the second stage experimental validation of the current FEA simulation [17]. This column was also made of the aluminium alloy AA6061-O, which had been used in the previous experimental validation findings of EA specimen-1.

Figure 8 shows the experimental and FE modular setups for EA specimen-2. This axial compression at the specimen is simulated in FEA in a quasi-static environment, as shown in Figure 8(a). Because the experimental setup is similar to the previous one, the same FEA approach is used here.

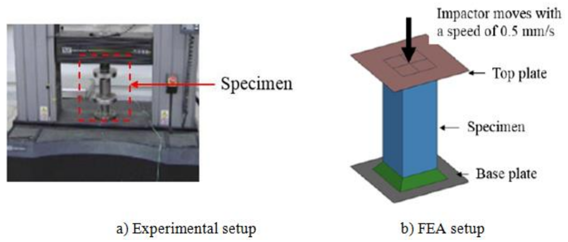


Fig 8. *Experimental setup [18], in addition to the current FEA setup for EA specimen-2*

Figure 8 shows the experimental and FE modular setups for EA specimen-2. This axial compression at the specimen is simulated in FEA in a quasi-static environment, as shown in Figure.

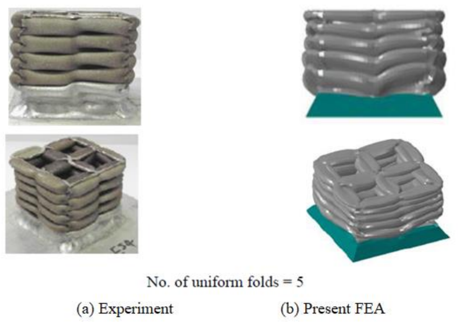


Fig 9. *Comparison of plastic deformation modes discovered by experiment and current FEA.*

Figure 9 shows a comparison of plastic deformation modes discovered by experiment and current FEA. In Figure 9, an axial crush force sample from the current FEA of this EA structure-2 is compared to experimental results [18]

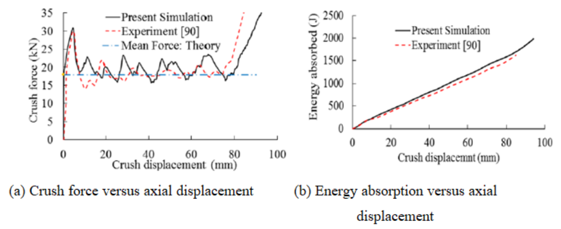


Fig 10. *EA specimen 1 crush force and energy absorption behaviour: comparison*

Table 2 provides a detailed comparison of crashworthiness evaluation parameters between experiment, FEA, and concept.[18]

Table 2. *Crashworthiness performance - present FEA versus EA specimen-2 experiment*

Parameter	Mass (kg)	Peak force (kN)	Mean force (kN)	TEA (kJ)	Crush stroke (mm)	CFE (%)	SE (%)	SEA (kJ/kg)
Present simulation	0.11	30.8	19.8	1.6	82.0	64.3	68.3	14.8
Experiment [90]	0.11	29.9	18.4	1.5	78.6	61.5	65.5	13.2
Theory [91]	0.11	-	18.0	1.5	82.0	-		16.5
% Difference in present simulation w.r.t. [90]	0	3.01	7.61	12.4	4.32	4.55	4.27	12.1

IV. CONFIGURATION DESIGNS FOR FRONTSIDE CRASH ENERGY ACCUMULATION

A sophisticated E A models being designed with an intention to maintain elevated crashworthiness thru common modes of assessment factors through numerical modes, these configurations being designed along 2 design variants, i.e., A, B types or sequences, former being a conventional rounded tubular model in a tube I tube A type of config along 4 variants, later is a unconventional sequence along sections thus made of mixture if curvi-linear fragments B type including concise distribution stiffened along prescribed point longitudinally, subsequent benefits, drawbacks of every mode being depicted here.

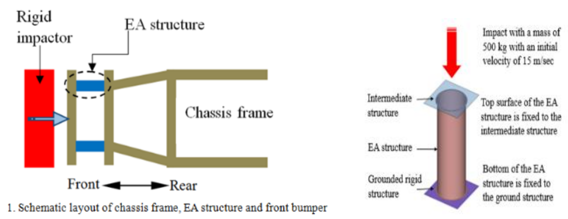


Fig 11. *FE model setup with boundary conditions*

A. Progressions of structural congifurations along A-type Tube-In-Tube- Approach

Newest desired EA design congifurations being visualised along Figure 8, config length being consistently proven as 240mm along an average measurand for almost EA designed entities along numerous mid-class- vehicles, the mass of every E A designed config being saturated about 0.5kg along consistent congifurations.

1. A1 Configuration:

Efforts in getting Fpeak down along rounded tubes being divided into 2 symmetrical tubes, 2.0mm of thickness along exterior tube, also 0.8mm core tube, about 90mm, 60mm mean diameter considerably on both exterior, interior tubes, with 0.5kg mass consistently throughout.

Visualizing F_{peak} about 231kN primarily almost symmetrical to 47g acceleration, crushing forces thus declines to 64kN at 24mm displacements sustaining primary folds decision on every tube.

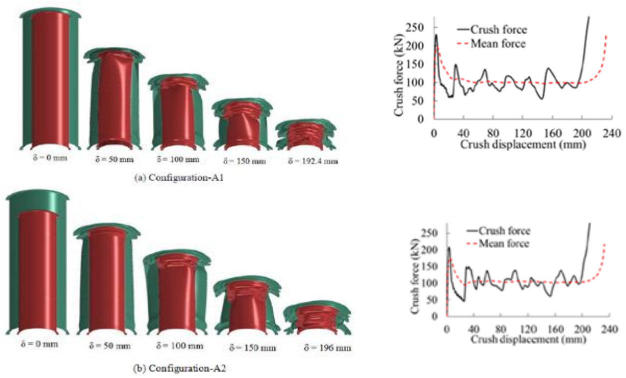


Fig 12. *Sectional view of EA structural configurations A1 and A2 crushing stages*

2. *A2 Configuration:*

Sectional visualisations in A2 config depicted along fig, also being obtained thru shortening longitudinally the interior tube thru 30mm from frontside. So as to descend in F_{peak}, as tubular exteriors alone influence primarily a crushing stroke of 30mm. Calculations of simulated entities of A2 config being estimated as decline of 206kN in primary F_{peak}, though tubular exteriors alone consume as impact of 30mm crushing stroke primarily, thus crushing force against displacement plot depicts in Figure 12. Out of the range folding designs of coaxial tubes ought to be functional consistently, plastic crushing being consistent till 196mm of crushing stroke thus, 4mm ahead of config-1 pertaining best along SE and CFE

3. A3 *Configuration:*

Through findings along congifurations 1,2, about knowing how shredding of symmetrical mass in varying portions affecting primary F_{peak} including CFE, further variations being made along advancing A3 config depicted in fig., thus A3 config is made of 2 coaxial tubes submerged against 3 ribs spaced longitudinally 1200, post trials of FEA, exterior tubes thickening 1.6 mm, as that of interior tubes as per the desired requirements with spacing of tubes being 90 and 50mm duly.

A design avails broader hints along the contacts against congifurations geometries including crushing forces design, towards making a suitable E A config design for suitable functionalities, symmetrical efforts delivered previously thru Zhang et al [19] against honeycomb designs

4. A4 *Configuration:*

Clearly specified along previous 3 configurations that elevated primary Fpeak being desirable restriction of EA designs, factors directly enforcing the seaters safety being critically elevated accelerative intensities, also predominantly unsuitable, subsequent restriction drawback being designs inherited character in avoiding plastic deformability post crushing stroke. Looking into gathered literatures visualises primary work done on designing E A models including medium primary F-peak, also S E crossing 90% ratios. Zhang et al [19] insisted ways along rounded sandwiched models having kagome core thus yielding against primary F-peak, concentrated a capable crushing character yielding minute S E about 66%. Observations of Reid [20] along capable plastic deformability processes also, Alghamdi [21] expanded initially on numerous collapsing configurations for influencing E A configurations availed few predominant advancing A4 config as depicted in Fig 13.

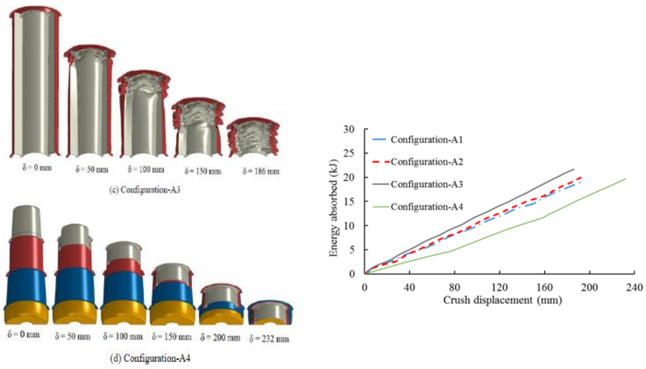


Fig 13. *Energy Absorption versus axial crush for all four EA structural configurations*

B. *Designing advanced fundamental structural configurations in amalgamation of generalised shapes (Type-B approach)*

1. *Configuration-B1 (base configuration):*

The initial configurations being received thru dividing a rounded tube into 2 half-round tubes of 2mm thicker with 70mm diameter, also spread rounded sections though end-to-end distance of 110 mm. The frontside flanged edges along every half-round tube being circled along a filleted radius of 12 mm in lessening prior Fpeak. The FE model being created including analysis axially influenced thru 500 kg mass empowered along E A structure amongst common velocity of 15.5 m/s. Fpeak about 153 KN thus being balanced along 31.2g acceleration thus triggers deformable crushing. Subsequent to consistent repetitive variations along crush force, mere focus on crush force plot, also advances along deforming crush visualises a decline through 153 KN @ stroke 14 mm, 60 KN @ stroke of 29 mm

Further crush force saturates along 60 kN thru every leftover existing crush stroke till 210 mm, thru this particular point, because of thickening along crushed areas, also decline in uncrushed portions, designs sustain additional deforming plastically, also ensures predominant stiffness, though crushing plastics being running till 210mm of strokes, thus SE along these EA designs being 84.2 % (thus, 240 mm total length).

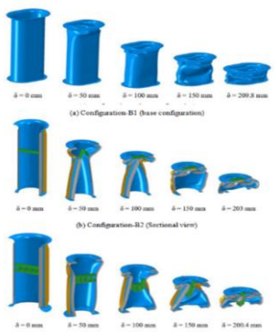
2. *Configuration-B2*

A joint half rounded tubes through 2 axe-linear strips of 1.8mm thick, main importance of these 2 strips being stiff enough along half-rounded tubes while crushing, also to lessen the capacity of variations along crush force. Frontside corners including flanges of half-rounded tubes being available along 12mm filleted radius in restricting basic fundamental F-peak. Half rounded tubes being submerged thru 3 ribs of longitudinal axes of thickness 1 mm, broadened 10 mm along exterior boundaries [19].

The crush force thus variants amongst 120 kN and 46 kN diverged thru active accelerations along extreme restricting 57% CFE. collective 203 mm crush stroke being obtained, thus, 84.6% SE, 17.25kJ TEA, thus crush performance pertaining to B2 config being proven to be similar to initial B1 config., in several indices.

3. *Configuration-B3:*

Thru the gathered records, along functionalities thru initial B1 config, B2 config being depicted along fig. 5.7(b) being received thru a joint half rounded tubes thru 2 axe-linear strips of 1.8mm thick, main importance of these 2 strips being stiff enough along half-rounded tubes while crushing, also to lessen the capacity of variations along crush force. Frontside corners including flanges of half-rounded tubes being available along 12mm filleted radius in restricting basic fundamental Fpeak. Half rounded tubes being submerged thru 3 ribs of longitudinal axes of thickness 1 mm, broadened 10 mm along exterior boundaries. Though half rounded tubes with ribs/webs deforming plastically along dual plots, enforcing minimal variations in crush forces along crushing as read thru crush observations in multivariate cellular columns/beams [19] thus interior submerged ribs/webs including rounded tubes plastically deform along dual orthogonal laminar walls, also triggers in neglecting amongst them thus providing sustainable crush forces.



4. *Configuration-B4:*

Variant entities deforming plastically along B4 configurations were depicted in Figure 5.8(d) including its responses plotted F – δ being depicted in figure, might be recorded as lessened thickness along half rounded tubes assists getting primary Fpeak about 115 kN, thus similar along 23.5g acceleration, altered interior cores thus advances stability along crushing, The varied inner core enhanced capability while crushing, importance of variations along crushing force lessened slowly thus advances crushing stroke stability about 80 mm, advancing C F E along ratios 71.4 %, declined Crushing stroke 197 mm thru 200 mm, materials crushed thickened because crushing along both edges. Such oddness in crush folding restricted S E about 82.1%, though crush force being variations along minute lowered crush forces of 70kN, the T E A dropped down by 16.2kJ. Decline in Fpeak, also variations in crush force presentation being predominant gatherings thru this congifurations, advances are necessitating S E and T E A.

5. *Configuration-B5:*

Variant extents, along deforming plastically against B5-config, are being depicted along figure. Plotted against crush forces and crush displacement i.e. (F - δ) being visualised in figure. Non-steady F_{mean} presented along F - δ plot enumerates collective energy accumulated against respective crush stroke. This configuration needs a beginning Fpeak of 150 kN towards infusing deformable crushing, saturating along an acceleration about 30.6 g, thus being eloped along catastrophic tolerance extents [22], The crush force thus variants amongst 120 kN and 46 kN diverged thru active accelerations along extreme restricting 57% C F E. collective 203 mm crush stroke being obtained, thus, 84.6% S E, 17.25kJ T E A, thus crush performance pertaining to B2 config being proven to be similar to initial B1 config., in several indices. Yet in another study, [23] FEA approach was employed to investigate fracture tolerance in ceramic based materials, which indicates that, crack energy release rate increases to maximum value relevant to inhomogeneity-matrix shear moduli and crack-inhomogeneity moduli.

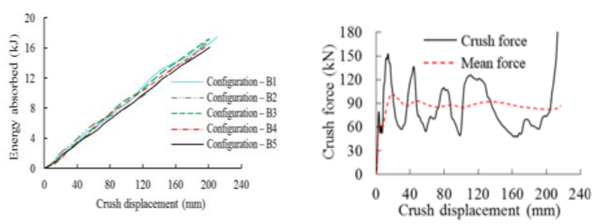


Fig 15: *Different stages during deformation of proposed EA structures based on type-B approach and Energy absorption versus axial displacement*

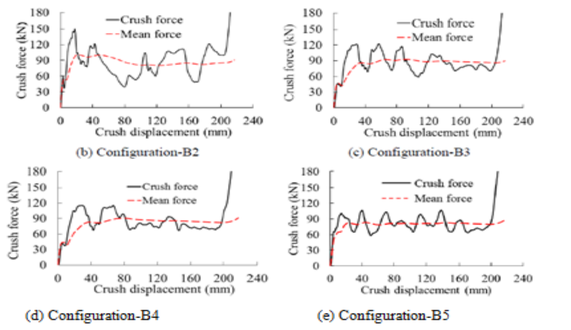


Fig 16: *Crush force and mean force with respect to crush displacement for proposed EA structural configurations based on type-B approach*

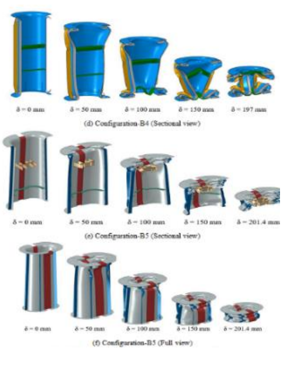
V. CONCLUSION AND SCOPE FOR FUTURE WORK

The predominant conclusions being elucidated along project as depicted here:

(a) Assessment/survey of crashworthiness: The quantum of total energy absorbed alone being non weighing criterion in crashworthiness along energy accumulating structures. The energy thus being optimal except carrying forward along crush force extents being consistent along the crush stroke.

(b) Geometrical functionality: Sectioning thru energy accumulating structure enumerating an anchoring responsibility along energy accumulation. Non dimensional standards in geometrical entities thus considerable along consistent crash energy accumulation. Sections designed along curved entities explore optimum stroke capability as its failed in processing consistency along crush force extents. Sections thus created along fragments (polygonal) express saturations in crush forces, since express comparatively lesser efficiency in stroke. Optimal geometries being optimal collectively along radius along linearity in fragments along permissible crush behaviours.

(c) Approaches in Deformation: Inversions along Tube approaches of plastic deformation visualises predominant functionality along every parametric assessment. Though shows better performance in all the crashworthiness assessment parameters. Permissible inversions along tubes need suitable geometrical consistencies, thickened gauges, suitable grades of material etc., currently ongoing theories along tubes under inversions being restricted along functional aspects amongst every metal but those metals possessing elevated ductile natures having optimal consistency amongst every parameter thus adapted.



(d) Specific E A advancements: Compositions along progressions in deformability and failure capabilities attributing an equivalent extents of crush forces without submersing the unique including consistent crush force trending covered with geometries.

(e) F E A methods: along the advancements in reliable acceptability's, non-linear F E A submerged analytical/numerical simulations being permissibly adapted along designing and framing atomized configurations in structures, thus collective efficient modes comprising sophisticated methodologies in geometry, modelling of damage processing along material adapted so as to promise the perfections against numerical/analytical simulations.

(f) Materials: possessing elevated strengths linearly doesn't affect or doesn't lead any confirmations of materials towards energy accumulating functionalities, thus materials posing elevated ductile characters thus favouring along energy accumulation comprising broader deformability plastically.

A. Scope for Future Work

The present work carried out being compromising precautions to the end users in the seater and cabinet under vehicular crashing, thus empowering, enforcing a continual modification in the project work so as to design/model the structure thus being idealistic against influences in energy accumulation as a major contribution along road safety.

The subsequent details were enforced for the futuristic approaches with this project work:

1. Roundness along edges, endings pertaining to tubes under crushing including ideal geometries cross sections being exhibited due to ease of producibility.
2. Suitability along sectional thicknesses, conjoined blanks thus welded, also the subsequent inversion forms like outside-in kinds enforces in elaborating deformability thru higher material strength.
3. Examinations along permissible hydraulically enforced hidden energy accumulation models for (i) concise restrictions along crushing forces, also (ii) capable safety of seater in contoured, intricate crashes.
4. Collective inversion, bending modes of deformability along with multivariate material configuration thus being exposed.

DECLARATION OF INTEREST

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

DATA AVAILABILITY STATEMENT (DAS)

No data will be shared/no associated data. As this paper is a part of my Research work, I do not want to publicize the results Until paper gets published in your journal.

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influenced its outcome.

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