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# The Experimental Investigation of Laser Welded Hydro Formed Tubular Applications for Automotive Vehicles Crashworthiness Assessment

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**ABSTRACT:** Recently, for many researchers, the evaluation of crash-worthy structures has turned into a prime area of interest. The researchers execute several evaluation processes experientially along with by simulating the characteristics as a result of their hunt for the finest energy-absorbing structure. In the vehicle industry, lightweight design is also a comparatively challenging problem. Application of Tailor Welded Blank (TWB) is a successful technique to attain a vital weight reduction whilst enhancing structure protection. Investigating the applications of TWB in automotive vehicles for frontal crash validation by three-point tubular bending along with tubular structure crushing specimens is the objective of this paper. To examine the crushing test analysis, a series of TWB tubes with varied thickness amalgamations are executed. The Laser Welding Process (LWP) is utilized to fabricate the TWB specimens. Peak Crushing Force (PCF), Energy Absorption (EA), Average Crush Force (ACF), Specific Energy Absorption (SEA), Crush Force Efficiency (CFE), and Average Bending Movement (ABM) are the indicators of crashworthiness, which are evaluated in the experiential analysis. As a consequence, the evaluation displays that for vehicle lightweight designing, the TWB is absolutely effectual as well as feasible.

**KEYWORDS:** Tailor Welded Blank (TWB), Laser welding process, three-point tubular bending, Tubular Structure crushing, and automotive vehicles.

## I. INTRODUCTION

The thin-walled structure has certain benefits like better EA capacity, lightweight, along with higher strength because of which it is extensively utilized as a structural component in vehicle bodies [1]. Lightweight, higher strength, lower price, higher reliability, stiffness, tremendous load carrying efficiency along with EA capacity are also the benefits of thin-walled structures [2]. The thin-walled structures' EA characteristics in bending obtained extensive attention since it is a significant crushing deformation mode [3]. By utilizing numerical, analytical, along with experiential methodologies, a wide range of studies has been performed to gain better knowledge about the methods of bending collapse of thin-walled structures [4]. In the automotive field, the TWB structures have seen broad applications throughout the years [5]. The TWB has potential applications, which provide solutions for certain industries like home appliances, alternative energy, rail cars, trucks, construction, shipbuilding, elevators, trailers, furniture, et cetera [6]. In this way, automotive manufacturers are attracted by the applications of various TWBs to manufacture lightweight components via higher-speed LWP along with consequent cold stamping methodologies [7]. Numerous sheets of metal with varied thickness as well as potency that are laser welded with their edges are utilized for the composition of TWBs [8]. In actuality, the vehicles' crashworthiness along with lightweight has been given more concerns. Fuel consumption along with environmental preservation is becoming an issue owing to the augmentation in vehicle production, which in turn demands the vehicular structures with lightweight. According to the data, 6-8% of reduction is found in fuel utilization with a 10% diminution of vehicle weight [9]. Nevertheless, to accomplish the automotive manufacturers' requirements, the applications of thin-walled components manufactured as of the monolithic automotive-grade were not appropriate [10]. Thus, several factors influencing the EA along with collapse, including the cellular dissimilarity (for absorbers with interior cellularization), cross-sectional shape, together with inter-tubular optimal radial distance (meant for the sectors of concentric circles) underneath various loading criteria are examined by these works [11]. Investigating the TWB or laser-welded blank applications in automotive vehicles for the frontal crash is the intention of the proposed work.



The paper's remaining part is structured as follows, the existing research works related to the current research study is being explicated in section 2, the experimental setup along with the procedure of the proposed study is being described in section 3, the experimental investigation's outcome is illustrated in section 4, and lastly, the work is winded up in section 5.

## II. RELATED WORK

Masahiro Saito *et al.* [12] concentrated on the Weld Metal's (WM) bendability (WM); in addition, analyzed it by conducting the bending test. In comparison, the laser-welded specimens' bendability was superior to that of the plasma-welded specimens. The WL's bendability was associated with the WM structure's homogeneity; thus, it was augmented with the elevation in homogeneity. The WL's surface roughness had no impact on the WL's bendability. With the WL width, the bending of the WL's bent surface was altered. Since the bent surface displayed an increased uniaxial stretching deformation, the bendability was augmented.

V. V. N. Satya Suresh [13] performed an experiential unit by utilizing a specific punch. This punch was divided into '2' segments, which were partitioned by insulating material. One part was utilized aimed at cooling the weaker material whilst the other segment is utilized for heating the robust material. The WL movement was decreased considerably with the selective methodology of heating as contrasted to the motion in a single punch. The effect of thickness proportions on the WL at varying temperatures was considered in this work. Experimentations were executed at room temperature along with increased temperature for the sheets with similar thickness. The experimentation's outcomes were contrasted with the numerical evaluation.

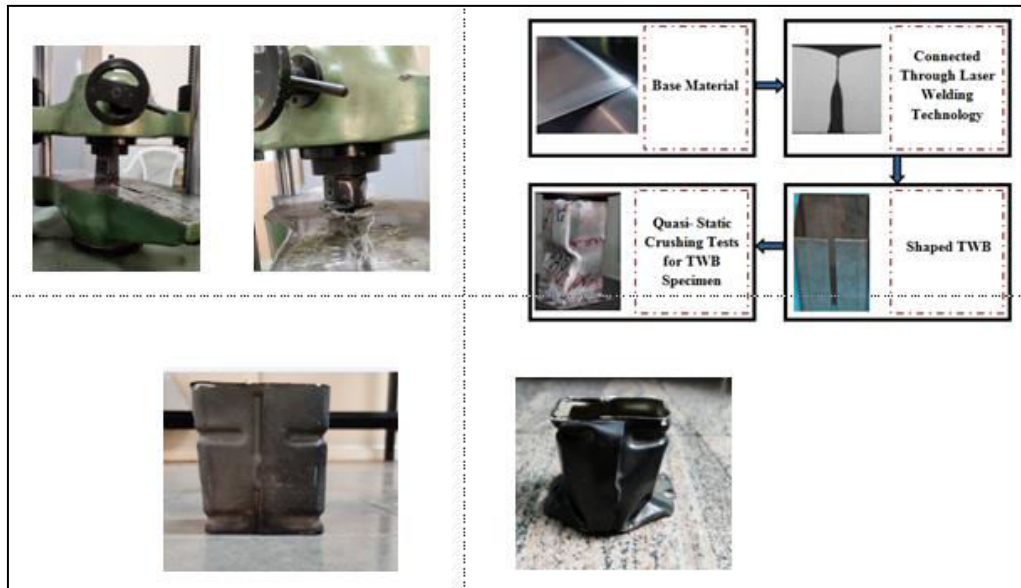
Huile Zhang *et al.* [14] introduced a highly pragmatic Finite Element (FE) modelling methodology. Next, by utilizing the 3-point and 4-point bending criteria, the bending features of Tailor Rolled Blank Top-Hat (TRBTH) as well as Uniform Thickness Top-Hat (UTTH) with equivalent mass were correlated. Subsequently, to investigate the crushing benefits of the TRBTH, numerical evaluations were conducted for the bending deformation. Lastly, to examine the thickness distribution's influence along with the thick zone's length on the 3-point in conjunction with 4-point bending features, a parametric study was performed. Consequently, it was established that the TRBTH's crashworthiness was influenced significantly by these parameters in a structure of varied deformation patterns.

LibinDuanet *al.* [15] produced a FE modelling methodology aimed at the TRB-TH structure. The Quasi-Static (QS) bending tests were conducted on '2' types of specimens to validate the FE methodology. Secondly, by utilizing the global sensitivity evaluation, the validated FE methodology was employed to study the TRB-TH structures' load-carrying efficacy along with the EA potency with differentiations in the constant thickness zone's thickness, lengths, together with the thickness transition zone's positions. Lastly, a multi-objective optimization design was implemented by incorporating the response surface mechanism along with the Non-dominated Sorting Genetic Algorithm (NSGA-II) to estimate the optimal thickness distribution. To design the vehicle body's TRB-TH energy absorbers, certain assistance was offered by the suggested methodology.

## III. EXPERIMENTAL PROCEDURE

QS-axial crushing along with bending experiments are certain fundamental experimentations that are executed on the Functionally Graded Thickness (FGT) thin-walled tubes with varied thickness distributions in this section. By utilizing the INSTRON material testing machine (Model 5985, maximum load-bearing of 150 kN), the thin-walled tubes' crushing along with bending actions are conducted for compression or flexure tests, correspondingly that permits the force versus displacement curves' direct recording. Figure 1 shows the specimen's preparation. Initially, to perform the TWB structures' welding process, the complete planar sheet was divided into specific shapes. Next, via the LWP, the patterned plates are connected, which strengthens the tiny heat-affected zone; thus it obtains advanced potency than the normally connected base elements. Next, the TWB thin-walled structures utilized for experimentations in this paper are formed by the welded plates. Lastly, in the INSTRON, which permits the force against displacement curves' direct recording, the QS crushing tests are executed.

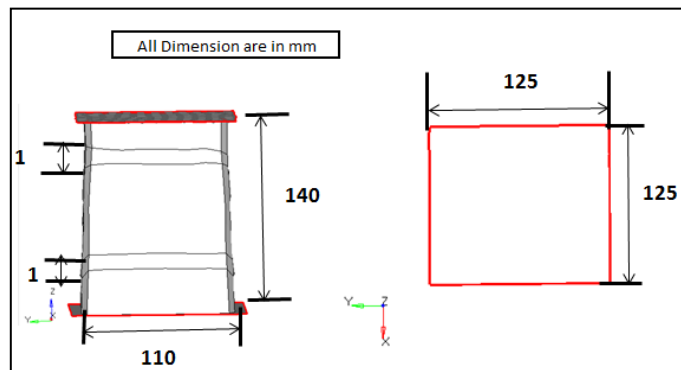




**Figure 1:** Preparation of specimens and pre and post test experimental deformed Result

### 3.1 Geometrical Description

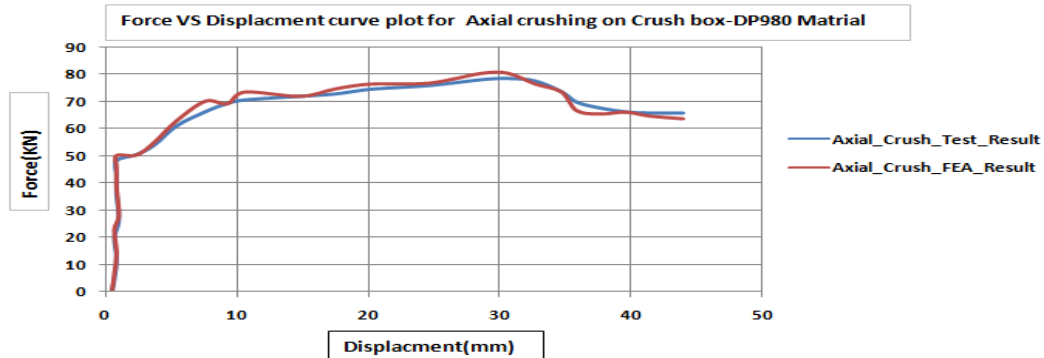
From the counterpart, the tubes are fabricated by a cutting operation with uniform thickness. The fixed (bottom) end's thickness value is proffered as the maximum value; likewise, the crushing (top) end's thickness value is defined as the minimum value. From the crushing end to the fixed end, the entire thin-walled tubes' thickness distribution is arranged linearly alongside the axial direction. The tubular specimens are acquired with a squared cross-section of 40mmx40mm; in addition, for all the cases, the thin-walled specimens' height is identical, which is equivalent to 100mm. Nevertheless, for various amalgamations, the tube-wall thickness varies from one another. As a consequence, by utilizing the QS-crushing tests, the tube is examined.



**Figure 2:** Tailor Welded Tube-Specimen CAD Design dimensions for Crush box

### 3.2 Quasi-Static Axial Crushing results

The test specimen is compressed at a regular speed in the QS testing. In a definite crash criterion, the structure is exposed to a reduction in crushing speed as of the starting speed and lastly to rest; thus, the QS test may not be an actual simulation of the crash condition. INSTRON model 1342 is a universal testing machine in which the QS axial crushing experiments are executed. In between '2' flat plates, the specimen is kept; in addition, a weight of 1000 kg is utilized at a constant speed of 6mm/min. Until 50% of the component is compressed, the load will be applied. In this, the EA along with max load utilized by the thin-walled tubes is studied.



Graph 1: Force Vs Displacement curve correlation for FEA and test specimen Crush box

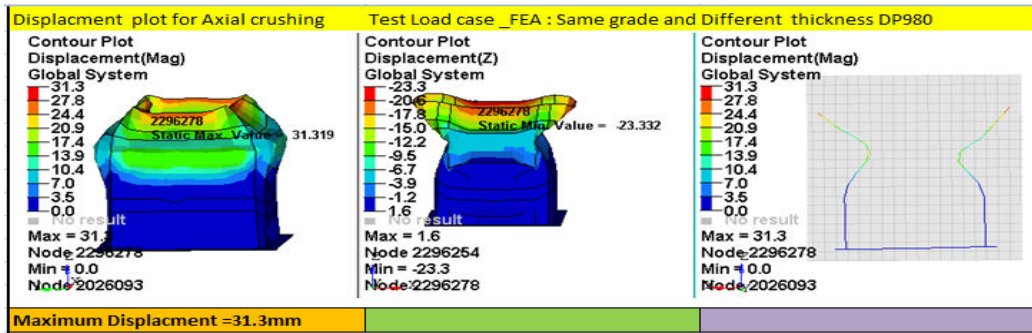


Figure 3: FEA Deformation plots for Crush box

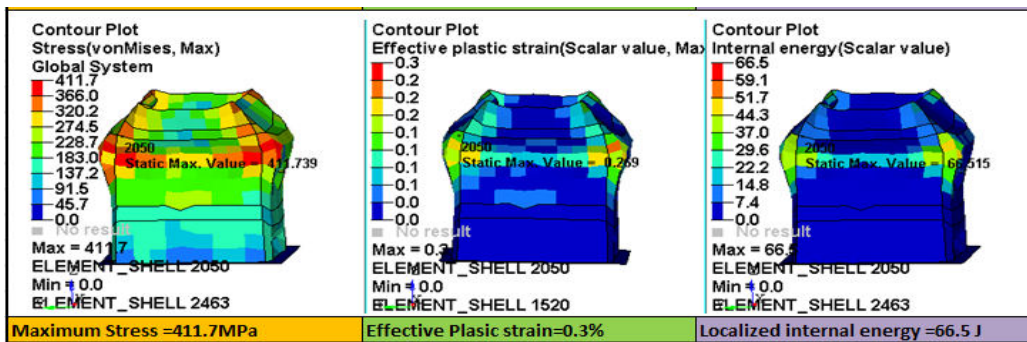


Figure 4: FEA Stress, strain and energy plots for Crush box

### 3.3 Indicators for Crashworthiness

Producing a manageable crushing pattern for increasing EA devoid of going beyond the permissible peak force to avoid occupant injury is the aim of the design of the crushing structure. To analyze the structures’ crashworthiness characteristics, apart from the EA and peak force, several other indicators have also existed. EA, ACF, PCF, CFE, SEA, and ABM are ‘6’ indicators being taken into consideration.

**Energy Absorption:** Regarding the force-displacement curve attained as of the crushing tests, the EA is derived.

$$EA = \int_0^{dt} k(x) dx \quad (1)$$

Wherein, the instantaneous crushing force is specified as  $k(x)$ , along with the crushing distance is signified as  $dt$ .

**Peak crushing force:** PCF is proffered as the instantaneous crushing force's maximum value.

$$PCF = \max(k(x)) \quad (2)$$

**Average Crush Force:** It is computed by the EA together with the provided deformation value  $\alpha$  is formulated as,

$$ACF = \frac{EA}{\alpha} \quad (3)$$

**Specific Energy Absorption:** The SEA is a significant indicator to compute EA capacity per unit mass of various structures, proffered as:

$$SEA = \frac{EA}{\delta} \quad (4)$$

Where, the total mass of EA structure is specified as  $\delta$ , normally, the structure in EA will be highly efficient with higher SEA.

**Crush Force Efficiency:** To compute the uniformity of a force-displacement curve, the CFE is utilized, which implies that a higher EA efficiency is produced with higher values. It is specified as,

$$CFE = \frac{ACF}{\max(k(x))} \times 100\% \quad (5)$$

**Average Bending movement:** ABM for the three-point bending is expressed as,

$$ABM = ACF \frac{g_1 \cdot g_2}{g_1 + g_2} \quad (6)$$

Where, the length of the zone is represented as  $g_1$  and  $g_2$ .

### 3.4 Properties of Base Materials

Two graded dual-phase higher-strength steel (DP800 and DP1000) sheets are regarded in this work. Silicon, carbon, chromium, manganese, sulphur, aluminium, nickel, phosphorus, molybdenum, and vanadium are the chemical compositions of these '2' base steel. In this study, '3' varied grade or thickness amalgamations are considered that are, DP600/1.0 mm, DP600/ 1.5 mm, along with DP800/1.0 mm. These combinations are acquired regarding certain points. They are, (i) the same thickness along with the identical grade material, (ii) the similar thickness and varied grade materials, (iii) varied thickness along with the same grade materials, and (iv) varied thickness and varied grade materials. For ease of evaluation, the tailored sheets DP800/1.0 mm, DP800/1.5 mm, and DP1000/1.0 mm are named P, Q, and R, correspondingly. Consequently, the different amalgamations are termed as PP (or QQ, RR), PQ, PR, and RQ, respectively.

### 3.5 Finite Element Modelling

The Finite Element Model (FEM) is utilized ubiquitously owing to the rising cost of performing experiments. The FEM is mostly utilized in the field of the automotive industry. Simulating numerous varied crash tests, providing a response



to several crash scenarios, and predicting the vehicles are performed accurately by the FEM. The time along with the cost of the testing process is minimized by this design; thus, provides effective protective decisions. In this, by utilizing the commercial code LS-DYNA, the FEM is implemented. It is executed in the LS-DYNA input card effortlessly devoid of pre-and post-processing time. It is an enhanced multi-physics simulation software package produced by the Livermore Software Technology Corporation (LSTC). It is extensively utilized in numerous fields like aerospace, automotive, civil engineering, together with bioengineering.

**IV. RESULT AND DISCUSSION**

Investigating the TWB applications in automotive vehicles for the frontal crash by 3-point tubular bending specimens and tubular structure crushing specimens is the aim of the work being proposed. By utilizing the CAE tools LS-DYNA, the investigation is stimulated. In this, by the amalgamation of various thicknesses of TWB, the examination is performed; for the current investigation, the crashworthiness metrics like PCF, ACF, EA, CFE, SEA, and ABM are evaluated. The mechanical properties for the base material are illustrated in table 1.

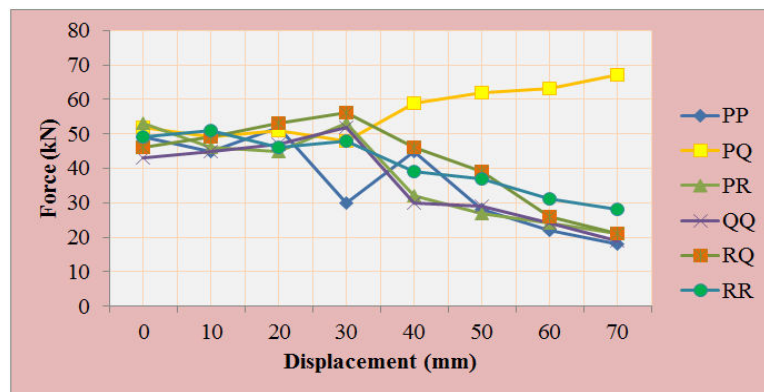
**Table 1:** Mechanical properties of the base material

Properties	DP800	DP1000
Young’s Modulus (GPa)	230	230
Poisson’s ratio	0.3	0.3
Yield stress (MPa)	521.30	896.12
Tensile stress (MPa)	865	1095

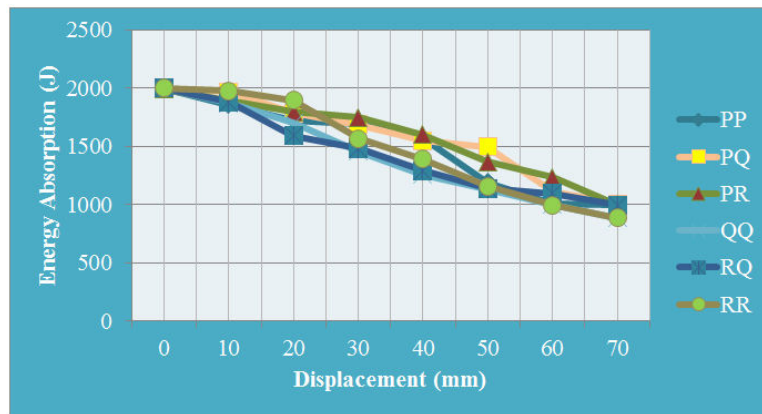
**Table 2:** Laser welding parameters of TWB combinations

TWB thickness combinations	Set power (kW)	Actual power (kW)	Welding speed (mm/s)
PP	1.0	0.96	40
PQ	1.5	1.45	30
PR	1.5	1.42	30
QQ	1.0	0.97	40
RQ	1.5	1.46	30
RR	1.0	0.97	40

The laser welding parameters for TWB combinations are shown in table 2. In this, the actual power is fixed. For the TWB with different thickness combinations, regarding the actual power, the set power is 1.0 and 1.5; similarly, the welding speed is 40 and 30mm/s.



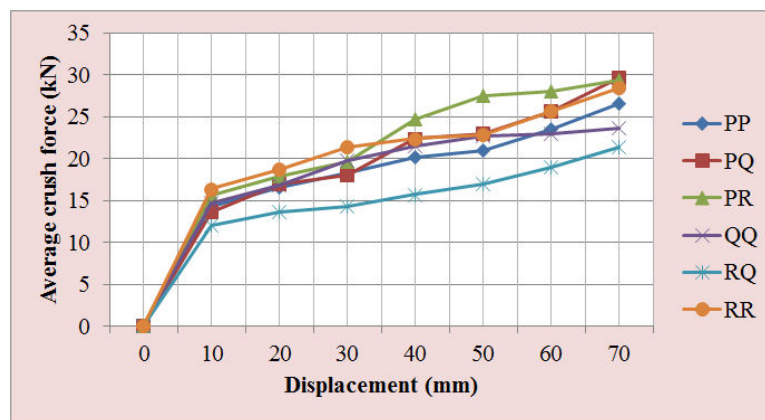
(a)



(b)

**Figure 2:** Analysis of the (a) peak force, and (b) Energy absorption for different TWB thickness combination

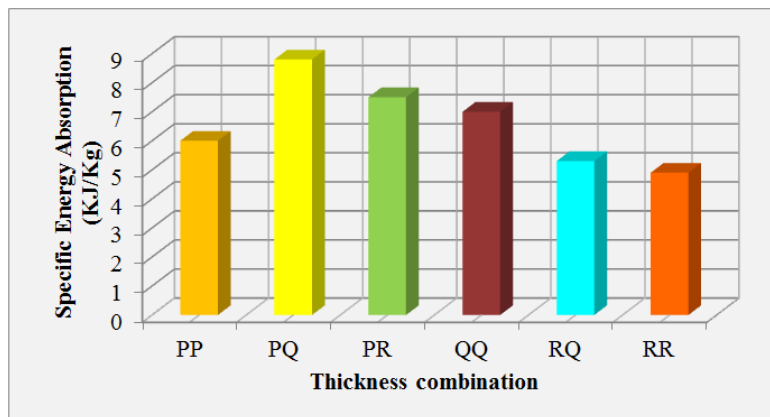
The peak force and EA of different TWB thickness combinations are demonstrated in figure 2. In correlation with the other TWB thickness, the PQ and PR combinations possess a higher peak force, which is being illustrated in figure 2(a). Consequently, regarding the variation of displacement, the peak force for the TWB is evaluated. The PQ thickness has a peak force of 67kN for the displacement of 70mm. The EA is assessed in figure 2(b). It is confirmed that the EA activities with varied thickness and material combinations are different from every single other. Here, a higher EA is obtained by the PP, QQ, and RR thickness combinations than the other thickness combinations.



**Figure 3:** Average crush force assessment

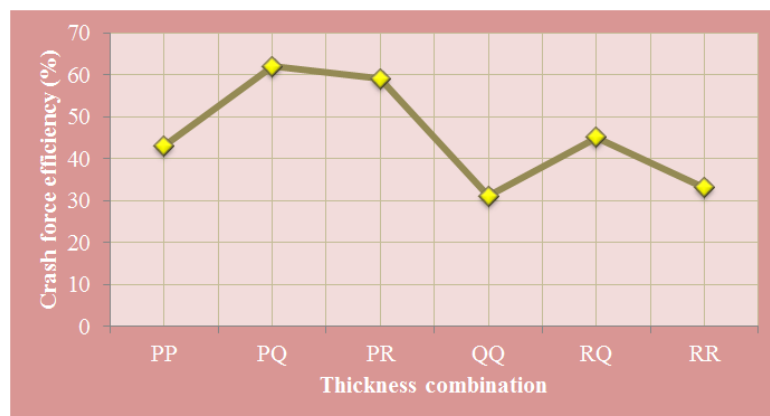
The ACF analysis for different TWB thickness combinations is depicted in figure 3. The ACF has differed for varied displacements. A higher ACF of 27045 kN and a lower ACF of 16.28 kN is obtained by the PR thickness and RQ thickness combinations respectively, for a displacement of 50mm, which shows that the different combination has both higher and lower performance.



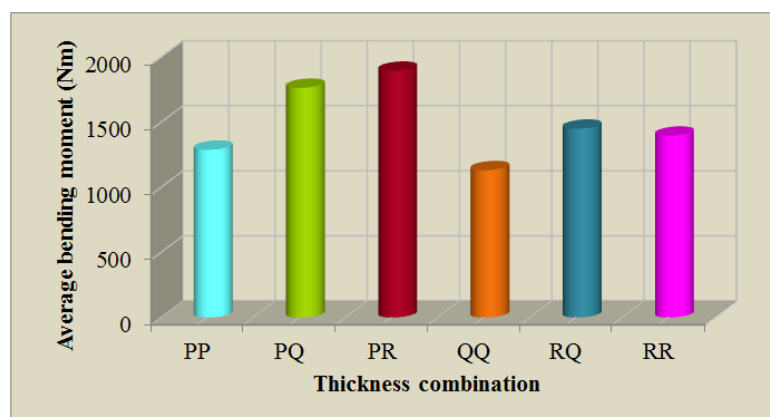


**Figure 4:** Specific energy absorption analysis

Figure 4 exhibits the correlation of SEA for different thickness combinations. The specific energy of different thicknesses of the TWB has better outcomes for all the ‘3’ bending tests.



(a)



(b)

**Figure 5:** Analysis of (a) crash force efficiency, and (b) average bending moment analysis for different TWB thickness combination

The CFE values of different thickness combinations of TWB are exhibited in figure 5(a). A higher CFE value of 62% is obtained by the thickness combination PQ than the other thickness combinations. The QQ thickness combination



obtained the lowest CFE of 31%. The ABM evaluation is displayed in figure 5(b). The PR has the higher value in terms of the ABM.

## V. CONCLUSION

Recently, to augment passenger safety and to decrease environmental emissions, the required balance betwixt enhancing the crashworthiness efficiency and obtaining the lightweight purpose of vehicle structures has obtained additional attention. The TWB along with Tailor Rolled Blank (TRB) has been extensively utilized in the automotive industry to attain lightweight along with crashworthiness vehicles. From this, the TWBs' properties have turned highly significant for the automobile industry. The crushing along with bending activities of the TWBs' thin-walled structures is explored in this study. In QS 3-point bending, the tubes are tested experimentally along with numerically. Different TWB thickness combinations' influences on the crushing characteristics are analyzed. The crashworthiness indicators like EA, ACF, PCF, SEA, CFE, and ABM are evaluated. It is established that a better balance betwixt those different crashworthiness conditions is provided by the TWB structures. The benefits of TWB with a reasonable enhancement are shown by the test outcomes. The outcomes display that the amalgamation of different thicknesses could influence the crashworthiness indicators crucially. According to the outcomes, it is confirmed that the TWB structures are considerably efficient to be an energy absorber intended for vehicle design. In the upcoming future, by utilizing more thickness combinations, the experiments can be expanded further.

## REFERENCES

1. LibinDuan, Zhanpeng Du, Haobin Jiang, Wei Xu, Zhanjiang Li, "Theoretical prediction and crashworthiness optimization of top-hat thinwalled structures under transverse loading", *Thin-Walled Structures*, vol. 144, pp. 1-12, 2019.
2. Guangyong Sun, Jun Tian, Tangying Liu, Xiaolei Yan, Xiaodong Huang, "Crashworthiness optimization of automotive parts with tailor rolled blank", *Engineering Structures*, vol. 169, pp. 201-215, 2018.
3. Zhanpeng Du, LibinDuan, Aiguo Cheng, ZhidanXu, Guangya Zhang, "Theoretical prediction and crashworthiness optimization of thin-walled structures with single-box multi-cell section under three-point bending loading", *International Journal of Mechanical Sciences*, vol. 157-158, pp. 703-714, 2019.
4. Zhixin Huang, Xiong Zhang, Chongyi Yang, "Experimental and numerical studies on the bending collapse of multi-cell Aluminum/ CFRP hybrid tubes", *Composites Part B*, 2019, Doi: 10.1016/j.compositesb.2019.107527.
5. Sun Guangyong, Tan Dongdong, LvXiaojiang, Yan Xiaolei, Li Qing, Huang Xiaodong, "Multi-objective topology optimization of a vehicle door using multiple material tailor-welded blank (TWB) technology", *Advances in Engineering Software*, vol. 124, pp. 1-9, 2018.
6. Aravind Kumar, Vijay Gautam, "Formability of tailor welded blanks of high strength steel a review", *Materials Today Proceedings*, 2021, Doi: 10.1016/j.matpr.2021.04.016.
7. Satish A. Bobade, Tushar Y. Badgujar, "Tailor welded blanks (TUBS) for a sheet metal industry", *International Journal of Advance Research and Innovative Ideas in Education*, vol. 3, no. 3, pp. 3771-3779, 2017.
8. Peister C, George R, Omer K, Worswick M. J, Malcolm S, Dykeman J, Yau C, Soldaat R and Bernert W, "Forming of an axially tailored automotive channel section through hot stamping of tailor-welded blanks", *Journal of Physics Conference Series*, vol. 896, no. 1, pp. 1-9, 2017.
9. Guangyong Sun, Tong Pang, ChenglongXu, Gang Zheng, Jie Song, "Energy absorption mechanics for variable thickness thin-walled structures", *Thin-Walled Structures*, vol. 118, pp. 214-228, 2017.
10. Bhupesh Singh Katiyar, Sushanta Kumar Panda, ParthaSaha, "Quasi-static crushing behavior of stretch formed domes of laser welded tailored blanks", *Thin-Walled Structures*, 2020, Doi: 10.1016/j.tws.2020.107288.
11. Ali Bigdeli, Mohammad DamghaniNouri, "A crushing analysis and multi-objective optimization of thin-walled five-cell structures", *Thin-Walled Structures*, vol. 137, pp. 1-18, 2019.
12. Masahiro Saito, Yoshiaki Nakazawa, KenichiroOtsuka, Masanori Yasuyama, Masatoshi Tokunaga and Tohru Yoshida, "Bendability of weld metal development of application technology of tailorwelded blanks 1st report", *Materials Transactions*, vol. 60, no. 10, pp. 2137-2142, 2019.
13. Satya Suresh V. V. N, SrinivasaPrakashRegalla, Amit Kumar Gupta, "Combined effect of thickness ratio and selective heating on weldline movement in stamped tailor welded blanks", *Materials and Manufacturing Processes*, vol. 32, no. 12, pp. 1363-1367, 2016.
14. Huile Zhang, Guangyong Sun, Zhi Xiao, Guangyao Li, Qing Li, "Bending characteristics of top-hat structures through tailor rolled blank (TRB) process", *Thin-Walled Structures*, vol. 123, pp. 420-440, 2018.
15. LibinDuan, Ning-cong Xiao, Guangyao Li, FengxiangXu, Tao Chen and Aiguo Cheng, "Bending analysis and design optimisation of tailorrolled blank thin-walled structures with top-hat sections", *International Journal of Crashworthiness*, 2016, Doi: 10.1080/13588265.2016.1246069.



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