An Experimental Investigation to Study Energy Absorption Capabilities of Foam Filled Tubes In Oblique Loading Using Taguchi Method

B.D.Deshmukh, P.W.Ingle, S.V.Bhaskar

Abstract- An Experiment is conducted to determine the effect of various parameters on performance of tube in oblique loading and optimize its crushing in the given environment..The Experiment was designed using Taguchi technique and the parameters like material density , tube thickness ,foam density and angle of loading were selected which have more influence on energy absorption ,specific energy absorption and specific total efficiency based on the available literature. The energy absorption was measured from the load –displacement graph obtained from UTM . The results obtained from this experimental process were analyzed using ANOVA and the empirical formulae predicting the energy absorption, specific energy absorption and specific energy efficiency were determined for tube under oblique loading.L16 array was used ,which is a full factorial array and conducted experiments using tube material, tube wall thickness, filler material density and angle of loading as the 4 factors with 2 levels , low and high.

Index Terms— ANOVA, Energy Absorption(EA), Interaction, Optimization, Taguchi method.

I. INTRODUCTION

Vehicle crashworthiness has been improving in recent years with attention mainly directed towards reducing the impact of the crash on the passenger. Efforts has been spent in experimental research and in establishing safe theoretical design criteria on mechanics of crumpling ,providing to the engineers the ability to design vehicle structures so that the maximum amount of energy will dissipate while the material surrounding the passenger compartment is deformed thus protecting the occupant inside. Different types of energy absorbing devices and structures are currently used ranging from metallic and composite materials. Each type of devices has their own advances and disadvantages. In last two decades, foam- filled structures are given much attention in research and development to be used in crashworthiness applications[1].Aluminum foam and polymeric foam are the candidates because of their specific strength and stiffness in addition of their capability to absorb energy in collision condition. Polymeric foam is preferred as it is cheaper and easy to manufacture. Foam filled tubes or structures have been introduced in the automotive applications to reduce overall weight of the vehicle, improve fuel economy and emissions along with reduced cost.

Manuscript Received on May, 2013.

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Mark Allen et al emphasize the use of low MDI structural foam in the automotive body structure to improve crash performance characteristics with weight reduction[2], Research into the collapse of thin-walled sections filled with foam fillers was first investigated by Thornton .He conducted quasi-static and dynamic axial compression tests for polyurethane foam-filled thin walled sections. He pointed out that noticeable increase in specific energy absorption (SEA) is possible with using thin sections made of high-density low-strength alloys such as mild steel[3], Similar findings were reached by Lampinen and Jeryan , who also investigated the effects of cross section geometry on the energy absorption characteristics[4], S.A. Meguid et al conducted finite element simulations and experimental studies to investigate the effect of key geometric parameters upon the crush behavior of PVC foam-filled thin-walled circular tubes[5], P. Raju Mantena et al studied three different density polymeric structural foams for their energy absorption characteristics under low-velocity uni-axial compressive loading and found that the highest density foam was most effective as filler inside the 0.8 mm thick hollow steel tube[6], Sigit P Santosa et al. studied the experimental and numerical crush behavior of aluminum foam-filled sections undergoing axial compressions during loading and modeled the interface[7], Hanssen et al. performed a comprehensive experimental study on filling thin-walled columns with aluminum foam and found a significant increase in crushing force[8], Based on design formulas developed from their experimental program me, Hanssen et al. Showed that significant weight savings are possible by utilization of aluminum foam filler[9], A.G. Hanssen et al develop a design formula to estimate the average crush force of the components [10], L.Aktay et al investigated the quasi-static crushing behavior of extruded polystyrene foam-filled Al tubes experimentally and numerically and highlighted several effects of foam filling in thin-walled Al tubes[11], Halit Kavi et al conducted an experimental study on the strengthening coefficient of Al and polystyrene foam filling in a thin-walled Al tube and concluded that regardless of the foam type and density used, foam filling changed the deformation mode of empty tube from diamond to concertina [12], Sujit Chalipat et al presents the potential use of structural foams in BIW at locations where section strength has an important role in crashworthiness. Use of structural foam in an in-production passenger car shows improvement in structural strength. Weight increase could be less than a steel reinforcement for similar improvement in strength depending on the nature of specific application [13], Zhibin Li et al performed tests on circular tubes made of aluminum alloy AA6063 under quasi-static axial or oblique loading to quantify the energy absorption of empty and aluminum foam-filled tubes under oblique

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loading with different loading angles and geometry parameters [14], A.E .Ismail et al performed tests on square tubes made of steel filled with polyurethane foam of different densities under quasi static oblique loading and, experimental results showed that both foam density and wall thicknesses are the key factor in determining the crashworthiness behaviors but when the structures are exposed to the oblique loading, energy absorption capability decreased accordingly as loading angles increase[1].

Most of the research mentioned above dealing with the axial energy absorption under quasi-static compression loads. Almost all researchers have studied the crashworthiness behavior of either steel or aluminum tubes with foam as filler using conventional experimentation. Therefore this paper attributes to study the energy absorption capabilities of foam-filled tubes of steel and aluminum under oblique compression forces using Design of Experiment (DOE) Taguchi Method. L16 array is used, which is a full factorial array and conducted experiments using tube material density, tube wall thickness, filler material density and angle of loading as the 4 factors with 2 levels, low and high. Constant crosshead displacement is used to compress the specimens quasi-statically at 10mm/min. Force versus displacement curve for each specimen is recorded automatically and the energy absorption capability is determined by measuring area under the curve using electronic planimeter.

II. METHODOLOGY

The major steps involved in Design of Experiments are [15]:

1. State the problem(s) or area(s) of concern.
2. State the objective(s) of the experiment.
3. Select the quality characteristic(s) and measurement system(s).
4. Select the factors that may influence the selected quality characteristics
5. Identify control and noise factors(Taguchi-specific)
6. Select levels for the factors
7. Select appropriate orthogonal array (OA)or OAs.
8. Select interactions that may influence the selected quality characteristics or go back to step 4(iterative steps)
9. Assign factors to OA(s) and locate interactions.
10. Conduct test described by trials in OA(s).
11. Analyze and interpret results of the experimental trials.
12. Conduct confirmation experiment.

III. EXPERIMENTATION

The Experiment was designed using Taguchi technique and the parameters like material density ,tube thickness ,foam density and angle of loading were selected which have more influence on energy absorption.UTM is used for testing. L16 OA was chosen using 4 factors with 2 levels because it gives a complete analysis of chosen factors.

Fig.3.1:Experimental setup

Table 3.1 Standard L16 Array(Coded)

Trial no	Material density (F_1) (Kg/m^3)	Tube Thickness (F_2) (mm)	Foam density (F_3) (kg/m^3)	Angle of loading (F_4) (degree)
1	1	1	1	1
2	1	1	1	2
3	1	1	2	1
4	1	1	2	2
5	1	2	1	1
6	1	2	1	2
7	1	2	2	1
8	1	2	2	2
9	2	1	1	1
10	2	1	1	2
11	2	1	2	1
12	2	1	2	2
13	2	2	1	1
14	2	2	1	2
15	2	2	2	1
16	2	2	2	2

where 1 indicates minimum and 2 indicates maximum level of parameter.

Table 3.2, Standard L16 Array(Actual values) with response

Trial no	F_1	F_2	F_3	F_4	R (KJ)
1	2700	1.5	0.0	15	3.09545
2	2700	1.5	0.0	30	3.57543
3	2700	1.5	60.0	15	3.82710
4	2700	1.5	60.0	30	3.40318
5	2700	3.0	0.0	15	7.83032
6	2700	3.0	0.0	30	4.55069
7	2700	3.0	60.0	15	7.60899
8	2700	3.0	60.0	30	6.04120
9	8000	1.5	0.0	15	6.18429
10	8000	1.5	0.0	30	4.57285
11	8000	1.5	60.0	15	4.90709
12	8000	1.5	60.0	30	5.73942
13	8000	3.0	0.0	15	12.9960
14	8000	3.0	0.0	30	7.19043
15	8000	3.0	60.0	15	14.7874
16	8000	3.0	60.0	30	5.86942

Table 3.3
General Linear Model: Energy absorbed versus Material density, Tube Thickness ,Foam density, Angle of loading .

Factor	Type	Levels	Values
Material density	fixed	2	2700, 8000
Tube thickness	fixed	2	1.5, 3.0
Filler density	fixed	2	0, 60
Loading angle	fixed		
2	15, 30		

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Table 3.4 Analysis of Variance for Energy absorbed, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Material density	1	31.095	31.095	31.095	7.97	0.017
Thickness	1	62.327	62.327	62.327	15.97	0.002
Filler density	1	0.302	0.302	0.302	0.08	0.786
Loading angle	1	25.718	25.718	25.718	6.59	0.026
Error	11	42.919	42.919	3.902		
Total	15	162.361				

S = 1.97529 R-Sq = 73.57% R-Sq(adj) = 63.95%

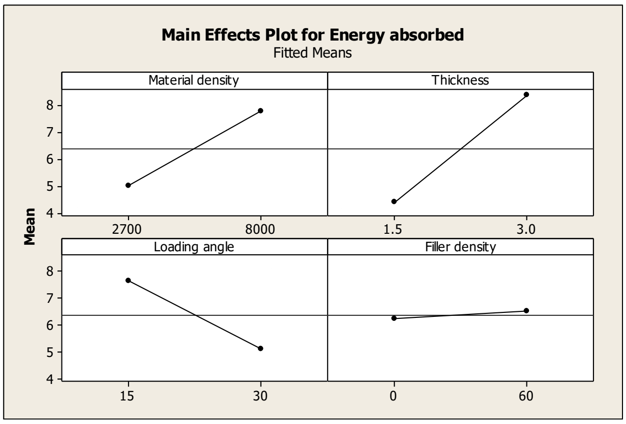

Fig 3.2: Main Effect Plot for L16

The energy absorption decreases with increase in loading angle and the same increases with increase in material density, thickness and filler density.

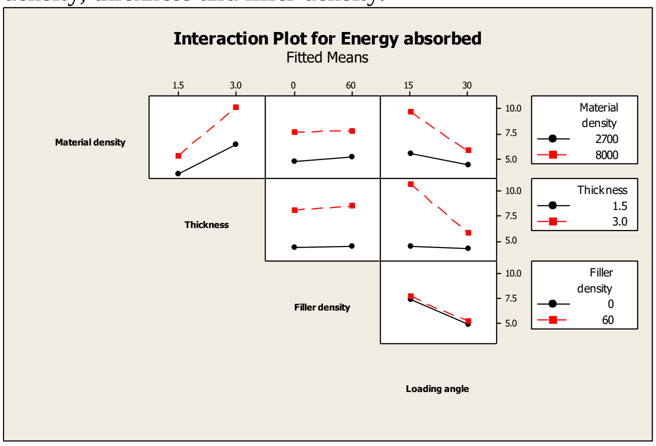

Fig 3.3:Interaction plot L16

The figure explains that factor loading angle has lot of influence on energy absorption, also lower levels of factors like material density,thickness shows less downfall of energy with increase in loading angle.

Table 3.5: Response Table for Signal to Noise Ratios Larger is better

Level	Material density	Thickness	Filler density	Loading angle
1	13.43	12.65	15.04	16.54
2	17.03	17.81	15.41	13.92
Delta	3.59	5.16	0.37	2.61
Rank	2	1	4	3

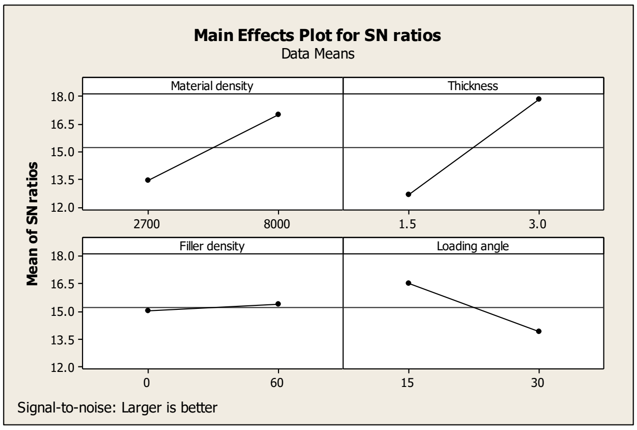

Fig.3.4 Main Effects Plot for SN Ratio

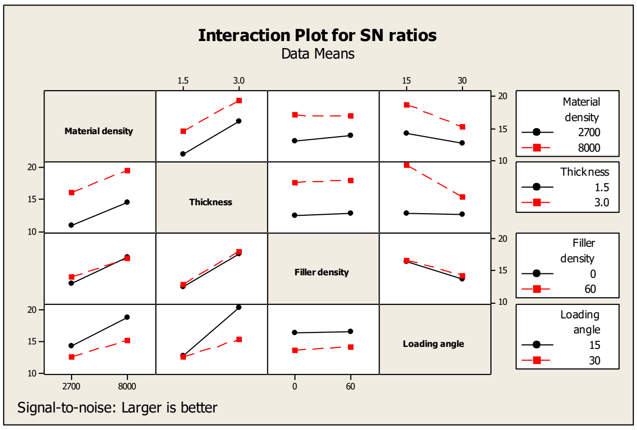

Fig. 3.4 Interaction Plot for SN Ratio

IV. CONFIRMATION TEST

The Optimum condition suggested by the analysis is material Al6063 (2700Kg/m^3), thickness 3mm, angle 15^0 with filler (60Kg/m^3) for given environment.

However L16 is full Factorial experiment and the above mentioned combination already exists and trial for the above has been conducted. Therefore separate conformation test is not required.

V. CONCLUSIONS

- Based on the analysis, tube thickness, material density and loading angle are seen to be the factors affecting the energy absorption.
- Increase in thickness and material density increases energy absorption.
- Increase in loading angle decreases the energy absorption.
- The Interaction between loading angle and filler density is statistically most influential.
- Again another interaction between loading angle and thickness is also found to be influential.
- Increase in Filler density helps to increase energy absorption for higher loading angle.

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