A Study of Ceramic Composite Materials for Bullet-proof Optimization by Using Taguchi Method

*Y.L.Chen, *C.K.Chu, *W.Y.Chuang, **S.H.Lee, ***K.C.Lee
*Department of System Engineer, National Defense University, Chung Cheng Institute of Technology ,**Hocheng Co. ,***Department of Textile Engineering, Chinese Culture University

Keywords: *Taguchi Method, Kevlar composite materials, controllable factors, orthogonal array*

Abstract

The purpose of this paper is to investigate the ballistic resistance capability of ceramic and Kevlar composite materials by using Taguchi method. Orthogonal array is adopted to organize the experiment, and then signal to noise ratio (S/N) analysis is used to realize the controllable factors effect to ballistic resistance. The contribution of each controllable factor is estimated by variance analysis (ANOVA).

The controllable factors considered in this paper include thickness ratio of ceramic to Kevlar, size of ceramic, and proportion of $z_r o_2$ *added. Each factor consists two levels, therefore L8(*2^3*) of orthogonal array is chosen to build 8 different level testing samples. Smaller-the-better characteristic is adopted because residue velocity is obtained from the test.*

Following the analysis procedure, the optimal combination of the chosen factors is then obtained. The study find that $z_r o_2$ *to add too much and reduce capability of ballistics, this ceramics : So the* $z_r o_2$ *5% of and Ceramic/Kevlar thickness ratio is 2:1,the ceramic panel size is 10cm × 10cm.*

1 Introduction

Tanks and armour tactics have undergone many generations of evolution over nearly a century. Although weapons systems and armour continue to be developed, many nations have reconsidered the need for such heavy weaponry in a period characterized. Ceramics composite materials are widely used in tank because of their high bulletproof performance. The utilization of composite materials armour in certain ballistic applications is increasingly preferred over conventional rigid metal armour systems because of its superior strength-to-weight ratio. The tank had hitting vertical face about 40% & 37% front face. So, the tank focal point should be protected in the vehicle and front face., Therefore, the tanks increase their protective capacities in the countries. After hitting, the armor can't be punctured. Therefore, various countries competitively study in protecting technology to protect strength armouredly.

It is a complex but quite interesting to study the ballistic penetration and perforation of fabrics. Armors, Cunniff [1], published concise surveys of the analytical models of penetration of projectiles into fabrics materials, which covered the major works that had been published. There are bulletproof plate, ceramic and fabrics composite materials to make the level III bulletproof plates in the world. However, the price of level IV plates bulletproof and prevents the special bullet attacking is too expensive. So, level IV plates needs high strong ceramics to make the cost lower

S. S. Morye, P.J. Hine, R.A. Duckett, D.J. Carr, and I. M. Ward proposed a model for the analysis of energy absorption by Polymer composite materials when impact by a projectile[2]. According to them, the energy absorption by the composite material under impact was classified into three models, respectively, Model 1 related to energy absorption when the composite material is destroyed due to tension; Model 2, the energy absorption of plasticity deformation under impact; and Model 3, the kinetic energy required for the conic deformation movement of the composite material under impact. Experimental and model calculations found out that the energy under impact was essentially consumed in Model 3. However, the model ignored the de-lamination factor and assumed that the destruction behavior of all the composite materials under impact must be evenly distributed. Even though such assumption might be a simple and fundamental model, it showed another direction for the study of the complicate destruction patterns of the composite materials.

The Ceramic to make passivation of bullet shell and stop advancing function, has reduced the bullet performance of penetration. If ceramic appear interface destroy, crackle and is it come back stress destruction, that loses and resists the performance of bullet-proof. In order to prevent this situation, need paying attention to bond resin, strength of ceramic, size, thick and resistance of stress wave【3】.

During the impact on ceramic have the result of the projectile damage or destruction, causing a decrease of penetration. On the border of the ceramic this damage occurs as cracks growth and the returning stress wave will decreases the performance of bullet-proof. During the study of the performance of ceramic, in order to prevent cracks growth and the returning stress wave on the ceramic during the impact , the ceramic dimension, thickness, bound form, and the ceramic amounts of resin material, ceramic Back Strength Wave Resistance Performance Received special attention

As Impact of a projectile on Ceramics parameters in the part of designing the parameters there is not quite complete data with the theoretical basis, so we used experiments test to understand the behavior of the ceramic under ballistic experiments. Still have access to all kinds of experiments parameters affect the result, often experimental are too many, time-consuming materials, in order to find the importance of the parameters and effects arising from the interaction is a systematic manner. So this study using the Taguchi method to reduce the number of experiments. Cost premise, testing experimental parameters related to the Resistance.

Taguchi Method, when a single material can not meet the needs, Combining two or more kinds of materials made of composite materials, can be overcome in the use of a single material performance gradually becoming a new trend of composite material. Through the composition of various materials matching not only changed the properties of a single, even be able to develop a good performance in order to achieve mutual materials matching the purpose of upgrading its use and economic value. In bullet-proof composite materials need to become part of the human and material resources to study . Impact of proyectile have many parameters to study, in addition to individual factors, also exist interaction between the parameters making the analysis more complex, Therefore, the use of Taguchi method to clarify the interaction between the factors and look for the best combination of parameters increase the reliability of this study

Steps of Tauchi Method :The parameters that influence the ceramic composite material behavior under ballistic impact are: composite of the ceramic, Thickness, type of resin, fiber types are too many, we must spend lots of time with the research and development costs to study. To solve this problem, this paper used the Taguchi method to improve the quality of engineering, the experimental steps outlined below:

(1)Material selection: According to the source material's availability and quality.

(2)Control factors selection: Basically three choices controllable factor, to predicted its quality characteristics under impact. Each factor have 2~3 levels.

(3) Recognizing the quality characteristics and the loss function.

(4)Selecting the appropriate orthogonal array for design experiments, and execute the impact test

(5)Formulate the data for the signal to noise ratio, quality characteristics and ANOVA analysis to find the best combination of factors.

(6)Making the best specimen combination testing to verify the best combination results.

2The Experment

2.1Materials

The ceramic material for impact test: the production process is base on 99.99% of Alumina powder(Al2O3) and zirconium powder(ZrO2).In this paper the arrange of this materials are with the weight ratio of 50% Alumina and 15%zirconia, Will be required for the content of zirconium to the alumina powder, remove high-temperature bonding agent, the mixture of organic matter, increase the intensity of the embryo, the final add sintering furnace sintering products

Al_2O_3 (Aluminium oxide), The powder size is 0.01mm into oxide to clay, then sintering ceramic, size is 100×100mm.So far, Aramid high efficiency ballistic fibers are popular. In this study, Aramid fiber pre-impregnating fabric produced by Kevlar® (Series No. K 735), using DuPont Kevlar ® filament ; epoxy, PVB(Thermosetting Polyvinyl Butyral 55±5g/m2, 12%); aramid fiber,1680 dtex/f1000; type K 735（Weave Style: Basket 2x2 Fabric Weight :510 (g/m2）, single side film coated prepreg, basis weight= 510±5 g/m2. One advantage about Aramid prepreg is that analysis results are not affected by changed containment of epoxy since epoxy containment in Aramid prepreg is consistent.

2.2 Test and Research

Extent of previous section by the use of the Taguchi method as a basis for planning experiments will avoid problems respect a limited cost, experimental short-period restrictions. Taguchi Method the analysis help is used as a tool for statistical analysis to choose the best process parameters and get the best combination composite

Fig. 1 85%/15% ceramic plate

Fig.2. 95%/5% ceramic plate

Fig. 3 ceramic/Kevlar specimen（**8** mm /**4** mm）

This research Al_2O_3ceramic collocation kevlar fabrics FRP to contrast proportion and difference. The test method to use DORP(Depth of Residual Pentration) model, The DORP(Depth of Residual Pentration) mode will measuring materials play the ceramic plate in rear materials after impact target, then with the regular speed shooting of 7.62mm 10.8g FMJ bullet, after the bullet impact the target plate（Fig 1~ Fig 3）, the kinetic energy of surplus is kicked into in following materials, checks bullet velocity and into depth of materials layer, it finds target materials ration and processes to appraise the ballistic performance. Because of the bullet impact plate, the back material was sunken depth in by the impact. The data can differentiate bulletproof performance of sample, as shown in Fig. 8& Fig.9

2.3 Experiment Photographs and illustrations

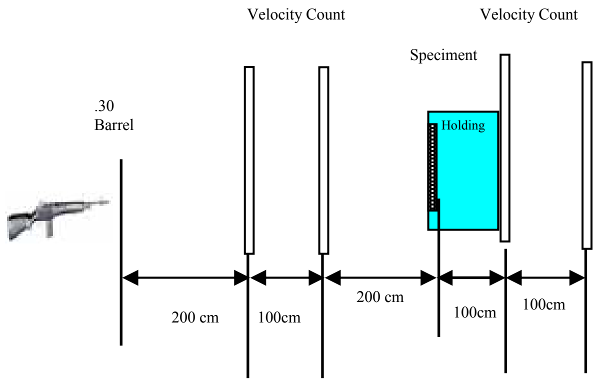

Fig.4. Test range configuration

Fig.5. The specimens and mounting frame

The test standard according to MIL-STD-662F【5】,as shown in Fig.4,and Fig.5 as mounting frame. Although the table under orthogonal array from testing order, the ceramic composite bullet-proof tests test data available for follow-up signal to noise ratio, quality characteristics and ANOVA analysis, to obtain the S/N response figure, the quality response characteristics table, , control factors and the contribution rate table, in order to determine the best selection factor, and the experimental validation.

3.Result and discussing

3.1 orthogonal arrays of experiments

The study with the least number of experimental test and desired process parameter setting has been developed.

An orthogonal array of experiments with the L8(2^7) of experimental test and desired process parameter setting has been developed. The experiments data to analyze.

3.1.1 The-Larger-the Better

Through Taguchi method and analysis of variance, ANOVA, the ballistic limits V50 parameters are bigger the better, but , ceramics are brittleness materials. So Find the V50 is degree of difficult and error, The paper use Total Absorb Energy（TAE）to compute that y, So y （Quality character）are most bigger the better.

3.1.2 Impact behavior phenomena

Evaluate bulletproof material judge the ability of many species, from the target impact can be understand it’s resistance characteristics , Fig.6 4 mm ceramic thickness (95% alumina and zirconia 5%), Fig.7 4mm ceramic 85% alumina and zirconia 15%). Comparing the two figures can be seen broken ceramic Fig. 5.8 the broken ceramic have relatively narrow scope, Also known by Table 5.4 in 5% zirconia ceramic composite have a better energy absorption. So better energy absorption of the ceramic material greater the destruction of the ceramic.

Fig.6 4mm thickness ceramic plane (5% $z_r o_2$)

Fig.7 4mm thickness ceramic (Alumina 15%)

The impact capability of a 5cmx5cm ceramic composite and a single 10cmx10cm ceramic composite id different because there is no way to transmit energy, as shown in Fig.8 5cmx5cm in the upper right-hand corner of the piece of ceramic is intact, as shown in Fig.9 5cmx5cm back side, confirm that the energy did not pass on these part, and results that tightness interface is also very important factor

Fig,8 5x5ceramic composite Sample test

Fig.9 5cmx5cm sample back

3.2 Experimental data and factor arrangement

L8(2^7) orthogonal array is used for the arrangement of test , this test are at random order. The residual data for ballistic testing, are shown in Table 1 .The velocity units are (m/sec),the initial velocity and terminal velocity can be measure by $F=\frac{1}{2}MV^2$ to find the energy absorption， where M=10.8 g is the bullet weight the results are described in the table 2

Table 1 Orthogonal experimental data table

Velocity M/S / Sample No.	Input V(1)	Output V (1)	Input V(2)	output V (2)
10X10Z5C4K8	810	526	861	722
5X5Z5C4K8	761	650	810	659
10X10Z15C4K8	775	634	836	677
5X5Z15C4K8	825	716	824	675
10X10Z5C8K4	846	346	857	366
5X5Z5C8K4	852	561	831	442
10X10Z15C8K4	815	375	853	338
5X5Z15C8K4	780	560	817	465

Table 2 Experiment dispose and energy calculate

Sample dispose / Sample No.	A	B	A×B	C	A×C	B×C	D	reduce energy y_{1i}	reduce energy y_{2i}	$\overline{Yi}$
10X10Z5C4K8	1	1	1	1	1	1	1	2029.918	1177.198	1603.558
5X5Z5C4K8	1	1	1	2	2	2	2	837.922	1186.732	1012.327
10X10Z15C4K8	1	2	2	1	1	2	2	1062.879	1287.033	1174.956
5X5Z15C4K8	1	2	2	2	2	1	1	898.634	1194.928	1046.781
10X10Z5C8K4	2	1	2	1	2	1	2	3188.600	3212.638	3200.619
5X5Z5C8K4	2	1	2	2	1	2	1	2199.829	2649.304	2424.567
10X10Z15C8K4	2	2	1	1	2	2	1	2801.260	3281.503	3041.381
5X5Z15C8K4	2	2	1	2	1	1	2	1577.180	2414.262	1995.721

※ On the table for the energy unit are Joules, $\overline{Yi}$ Defined as the average energy absorption, D as error.

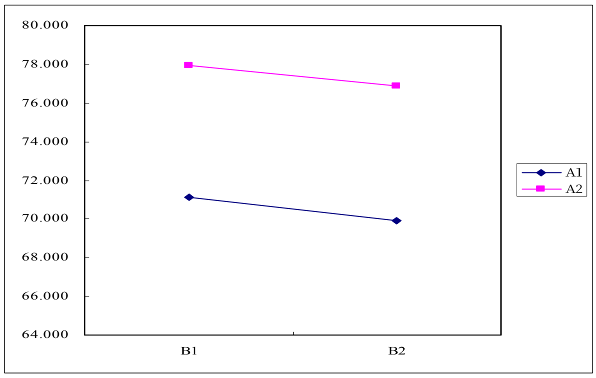

Fig.10 AxB interaction describe

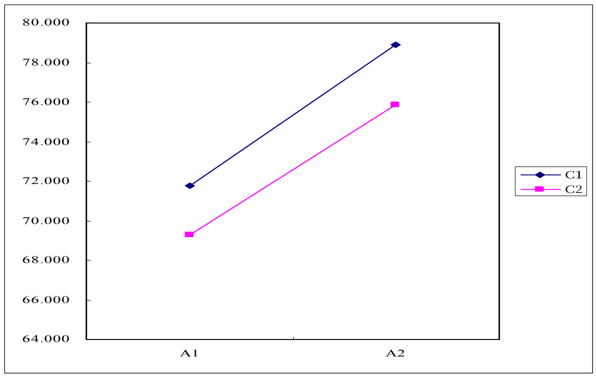

Fig.11 AxC interaction describe

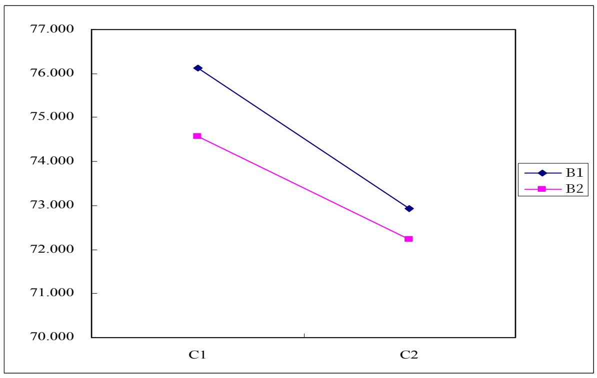

Fig.12 BxC interaction describe

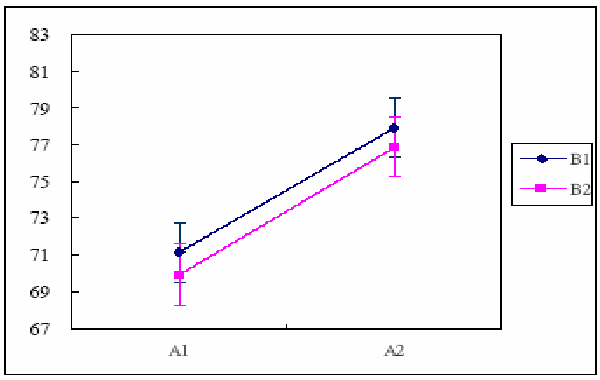

Fig.13 BxA interaction describe

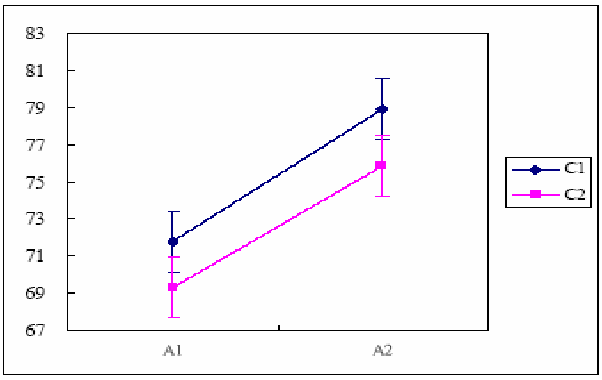

Fig.14 CxA interaction describe

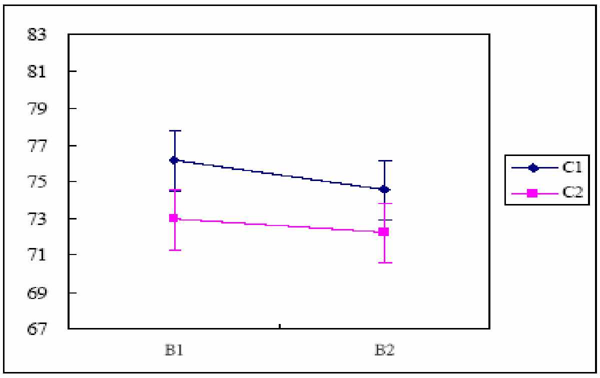

Fig.15 CxB interaction describe

From the Table 3 we can have the A factor and B factor interaction describe in the Fig. 10-15

3.3 S/N response table

From the fig. 10 the larger the better analysis of the data can find the S/N ratio describe on table 3.Using the table 3 we find the response ratio in table 4 .

Table 4 signal to noise ratio table show the response control factor on ceramic composite materials under ballistic impact in the following order: Factor A > Factor C > Factor B.

Table 4 can be drawn the signal to noise ratio-response. Because the use the large the better analysis the table 4 (a standard baseline values), or Fig.16 map, shows the best combination of parameters, that are: A2, B1, C1 factor levels, on behalf of its significance as follows:

A2：ceramic and Kevlar thickness ratio 2:1(ceramic is 8mm、kevlar is 4mm)。

B1： 95% alumina and 5% Zirconia

C1：10cmx10cm ceramic

Table 3 orthogonal arrays S/N specific value

Sample dispose / Sample No.	A	B	A × B	C	A × C	B × C	D	SNi (db)
10X10Z5C4K8	1	1	1	1	1	1	1	73.133
5X5Z5C4K8	1	1	1	2	2	2	2	69.137
10X10Z15C4K8	1	2	2	1	1	2	2	70.431
5X5Z15C4K8	1	2	2	2	2	1	1	69.428
10X10Z5C8K4	2	1	2	1	2	1	2	79.136
5X5Z5C8K4	2	1	2	2	1	2	1	76.724
10X10Z15C8K4	2	2	1	1	2	2	1	78.692
5X5Z15C8K4	2	2	1	2	1	1	2	75.033

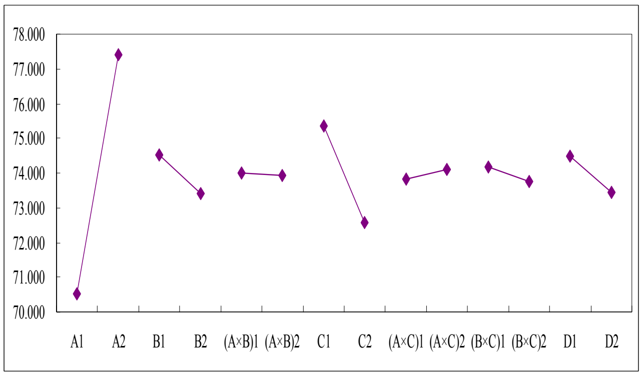

Fig.16 S/N rate response table

Table 4 S/N response

control factors / level	A	B	A × B	C	A × C	B × C	D
1	70.532	74.532	73.999	75.348	73.830	74.182	74.494
2	77.396	73.396	73.930	72.580	74.098	73.746	73.434
Max-Min	6.864	1.136	0.069	2.768	0.268	0.436	1.060
Rank	1	3	7	2	6	5	4

From table 4 S/N we get the S/N average (η_m)=73.964 Decibels (db)。

3.4Response of Control factors under ballistic impact

The papers the control factors are ceramic and Kevlar thickness ratio, amount of zirconium oxide, Ceramic combination, these factor will be analyze by the S/N ratio and ANOVA analysis, to understand the factors response and its contribution factor on the behavior under ballistic impact. As shown Fig. 17 are Predicted data & confirmation run data confidence intervals . The Fig. 18 details this response.

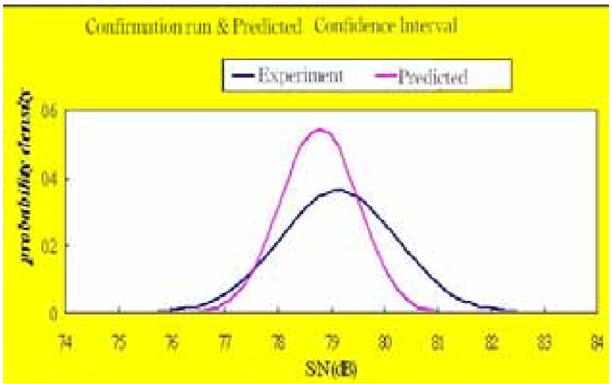

Fig.17 Predicted data & confirmation run data confidence intervals

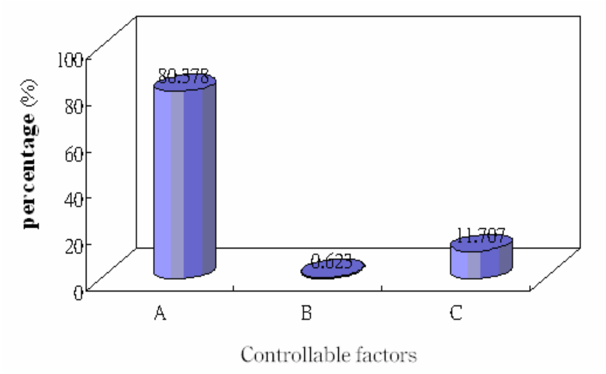

Fig.18 Controllable factors& contribution rate

Conclusion

(1) In this paper, through S/N ratio and ANOVA analysis to predict the optimal combination find the best combination is A2, B1, C1; and by verification experiment the analysis and results prove correct, corroborating that the Taguchi method can effectively predict the optimal parameters of the standard

(2) Using Taguchi Method orthogonal array for planning experimental design, the experimental cost and time savings were very effective and more parameters to be use in a future.

(3) Throughout the experimental procedure and results we found that the ceramic layered gives very good results. And the ceramic fragments will not damage the instrumentation or injury to laboratory personnel rerulting in a best result of the ceramic composite bulletproof capability.

(4) During the study we found that that a large amount of zirconia reduce the energy absorption capability, Therefore, alumina and zirconia do mix, Alumina need to have certain amount.

References

[1] Cunniff PM. "An analysis of the system effects in woven fabrics under ballistic impact, *Textile Res. J*.vel.62,9,pp 495-509, 1992

[2] Morye, S. S., Hine, P.J., Duckett, R. A., Carr, D.J., Ward, I. M. "Modelling of the Energy Absorption by Polymer Composites upon Ballistic Impact", *Composites Science and Technology*, Vol. 60, 12,pp 2631-2642,2000

[3] YANG Chao; CHEN Jiong"Research on bullet-proof performance of aluminium/ceramic particles composite materials" ,*Institute of China Ordnance Industries*, Vol.23, 1,pp8-10,2003

[4] Sugimoto S., Fukuda H. and Katayama T. "The title of the conference paper". *Proceedings of Conference Title*, where it took place, Vol. 1, paper number, pp 1-11, 2004.

[5] Department of Defense. MIL−STD−662F, *DoD Test Method Standard, V50 Ballistic Test for Armor*. 1997.