# Taguchi based – fuzzy method optimization of proposed ultra-high strength steel /UHMWPE helmet under variable impactor conditions

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## Abstract

Ultra high strength steel (UHSS) is known for its high strength, high modulus and high energy absorption ability through plastic deformation. However, it is less appealing for lightweight applications due to it relatively high density despite their cheap price. Therefore, all advanced helmets are made from advanced lightweight polymeric materials which are very expensive. The advantages of these classes of material can be harnessed by combining the synergies between them. This study seeks to investigate the application of thin layers of high strength steel and ultra-high molecular weight polyethylene (UHMWPE) in designing cheap and low weight helmet under impact application. Optimization of the proposed helmet under variable impact conditions has been performed through a Taguchi-based fuzzy logic approach. The optimization study investigated the integrity of the proposed helmet considering variable helmet weights, impact velocities and impactor masses. Optimum combinations of these design parameters were obtained through the utilization of Taguchi orthogonal array matrix. Maximization of fracture energy and reaction forces between inner shell and cushion of helmet were considered as criteria for the optimization procedure. Input data for the optimization process were obtained through numerical simulation using the explicit finite element program - LS-PrePost. The study concludes on the potential application of high strength steel/UHMWPE laminate system in designing cheap helmet for sporting activities and also by extension in stopping lower class projectiles.

## 1. Introduction

The human head is a delicate part of the body. High impact on the human head in known to cause long term traumatic conditions which at worse cases leads to death. In America for instance about 5 percent of people who encounters traumatic brain injury (TBI) lose their lives. Protection of human head against impacts dates back to the 19th century where the major material used in constructing helmet was steel. However, the use of steel helmet against impact from fragments had some drawbacks, the prominent of those was its high weight which made it uncomfortable to use. Lightweight helmets from composite materials have erupted rapidly to mitigate the weight setback. Reinforced fiber composite materials have since then been the major alternative materials in designing advanced helmets for various applications. Preference of fiber composite helmets is attributable to their light weight, high flexibility and high energy absorption capacity. However, there is a high cost involved in manufacturing these advanced helmets. An alternative approach in designing advanced helmets at relatively lower cost without compromising on the safety and weight constraint is highly recommended. In addition, the study factors into consideration variable impact scenarios that a typical helmet may be subjected to through an optimization approach. Flow chart for the study is as shown in the figure below.

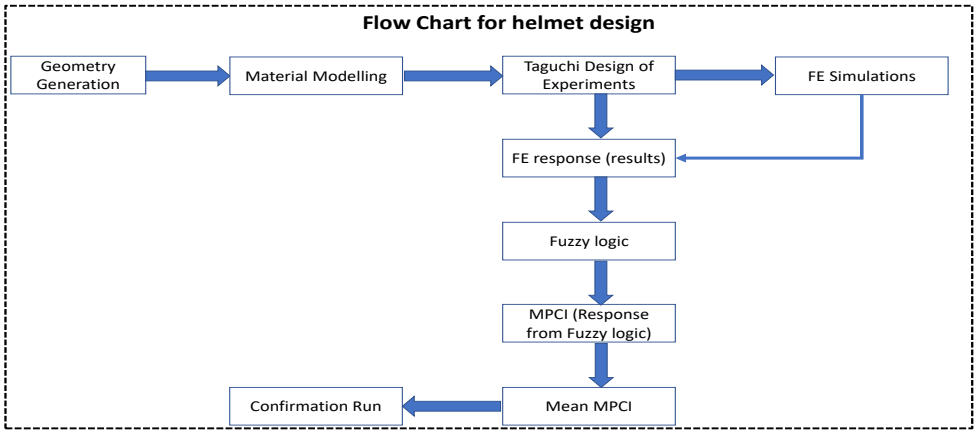


Figure 1. Flow chart for the helmet design

## 2. Results

The Taguchi-based fuzzy logic method has been used to optimize the design of a proposed steel-UHMWPE helmet. Obtained finite element (FE) analyses simulation results had solely been the source of data for the optimization evaluation. Some findings from the numerical investigation are as outlined below:

a. Thickness of helmet shell (steel/polymer ratio) has been varied to investigate it effect on energy absorbtion
b. Optimum energy absorption by confirmed helmet configuration is shown to be about 800 Joules, which suggests its potential application against BR2 projectile according to BS-EN 1063 standards.

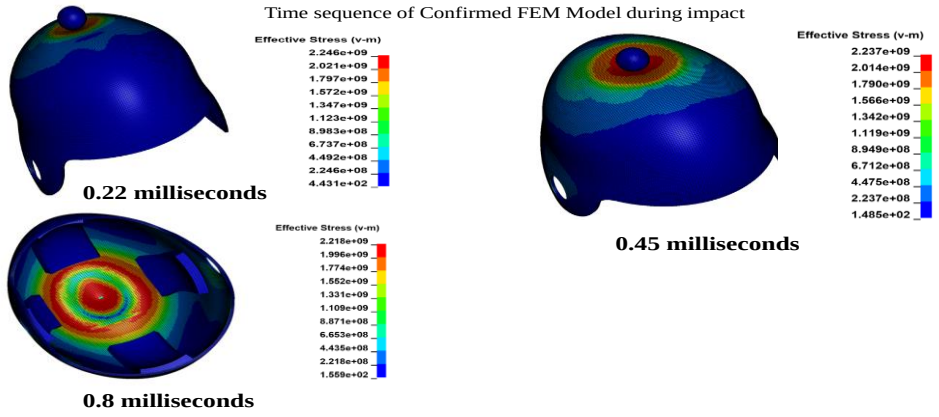


Figure 2. Time sequence during impact event of optimum configuration.

## 3. Conclusions.

Various impact conditions involving velocity ranges of 10 to 40 m/s for variable impactor masses of 0.25 – 1 kg on four different helmet configurations has been investigated. A proposed helmet with competitive weight equivalence and cheap cost has been designed through numerical simulations.