EXPERIMENTAL CHARACTERIZATION AND NEURAL NETWORK PREDICTION OF DYNAMIC BEHAVIOR OF ZTA WITH $SrCO_3$ AND MgO

by

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LIST OF ABBREVIATIONS

ZTA	-	Zirconia toughend Alumina
YSZ	-	Yttria stablized Zirconia
SHPB	-	Split Hopkinson Pressure Bar
EDX	-	Energy Dispersive X-ray
FESEM	-	Field Emission Scanning Microscope Electron
SEM	-	Scanning Microscope Electron
XRD	-	X- ray diffraction
Wt%	-	Weight percentage
ICDD	-	International Center For Diffraction

LIST OF SYMBOLS

A_b	cross sectional area of the bar
E_b	Young's modulus of the bar
C_b	longitudinal elastic wave speed
P	Pressure
V	Velocity
σ	Stress
ε	Strain
$\dot{\varepsilon}$	Strain Rate
A_s	Cross-sectional area of the sample
L_s	Length of the sample
δ	Misfit
r	Radius
ϑ	Poission's ratio
σ_y	Yield strength
t	Thickness of the sleeve
D	Outer diameter of the sleeve
H	Vickers hardness
k_{Ic}	Fracture toughness
l_e	Effective crack length
P_r	Porosity
e^n	Total error for *n-th* iteration
d_j^n	Target output
y_j^n	Network output

EKSPERIMENTAL PENCIRIAN DAN RAMALAN RANGKAIAN NEURAL UNTUK SIFAT DINAMIK ZTA DENGAN $SrCO_3$ DAN MgO

ABSTRAK

Bahan seramik digunakan dengan meluas dalam alatan ketenteraan kerana sifat-sifat bahan yang menarik seperti kekerasan yang tinggi dengan ketumpatan yang rendah dan kekuatan mampatan yang tinggi. Walau bagaimanapun, untuk mereka bentuk dan pemilihan bahan seramik yang sesuai memerlukan pengetahuan yang mendalam mengenai perlakuan dinamik seramik. Beberapa kajian telah dilakukan ke atas perlakuan dinamik seramik, namun begitu kebanyakan kajian yang dilakukan hanya terhad ke atas seramik konvensional seperti Al_2O_3 , B_4C, SiC. Atas sebab ini, ramalan ke atas perlakuan dinamik bagi komposisi seramik baru adalah sukar dan untuk beberapa ketika ia adalah mustahil. Dalam kajian ini, sifat-sifat mekanikal dan perlakuan dinamik ZTA dikaji. Kajian perlakuan dinamik ZTA meaggunakan alatan SHPB yang di ubah suai (memasang 'pulse shaper' dan bahan di letakkan antara plate we. Kesan penambahan YSZ (10-40 wt.%) ke atas sifat-sifat bahan ZTA turut dikaji secara dinamik menggunakan SHPB. Penambahan 20 wt.% YSZ ke dalam ZTA menunjukkan sifat-sifat bahan dan perlakuan dinamik yang optimum. Kesan penambahan $SrCO_3$ (1-5wt.%) ke dalam ZTA dengan 20 wt.% YSZ dan pembentukan fasa ($SrAl_{12}O_{19}$) mempengaruhi keliangan dan keliatan retak. Pembentukan fasa ini meningkatkan keliangan dan justeru merendahkan prestasi dinamik komposit tersebut. Penambahan MgO (0.2-0.9 wt.%) ke dalam ZTA dengan 20 wt.% YSZ menyebabkan pengecilan saiz butir dan mengakibatkan peningkatan kekerasan. Kajian juga dilakukan bagi keadaan bebanan dinamik yang berbeza ke atas ZTA dengan 20 wt.% YSZ dan 0.2 wt.% MgO. Perlakuan dinamik ZTA diramal menggunakan 3 kaedah mesin pembelajaran yang berbeza iaitu 'Multilayer Perceptron (MLP)', 'Time Series'

dan ‘Supporting Vector Regression (SVR)’. Setiap kaedah ramalan dibandingkan, dan kaedah ‘Time Series’ melalui rangkaian neural menunjukkan keputusan terbaik yang sama dengan data eksperimen.

EXPERIMENTAL CHARACTERIZATION AND NEURAL NETWORK PREDICTION OF DYNAMIC BEHAVIOR OF ZTA WITH $SrCO_3$ AND MgO

ABSTRACT

Ceramics materials are extensively used in armor applications for their attractive properties such as high hardness, low density and high compressive strength. However for designing and selection for appropriate ceramic armor material, a deep knowledge about the dynamic behavior of ceramic is necessary. A number of research has been done on dynamic behavior of ceramic, unfortunately most of work focused on the conventional and limited ceramics (such as Al_2O_3 , B_4C, SiC). For this reason prediction of the dynamic behavior of the new composition of ceramics is difficult and some time is impossible. In this work, mechanical properties and dynamic behavior of ZTA are being investigated. For studying the dynamic behavior of the ZTA, SHPB apparatus is modified (using pulse shaper and sandwich the sample with WC platen) and used. Effect of different amount of YSZ (10-40wt.%) on their properties of ZTA is also investigated dynamically using SHPB. ZTA with 20 wt.% YSZ shows the optimum properties and also their dynamic behavior. Effect of $SrCO_3$ (1-5wt.%) added to the ZTA with 20 wt.% YSZ and the formation of new phase ($SrAl_{12}O_{19}$) on porosity and fracture toughness is of interest. The formation of this phase increases the porosity and hence decreases the dynamic performance of the composite. An addition of MgO (0.2-0.9wt.%) to ZTA with 20 wt.% YSZ resulted a reduction in grain size and consequently increase the hardness. Further investigation on different dynamic loading condition on ZTA with 20 wt.% YSZ and 0.2wt.% MgO were also conducted. The dynamic behavior of representative ZTA is predicted by three different machine learning methods (Multilayer Perceptron (MLP), Time Series and Supporting Vector

Regression (SVR)). The predictions are compared to each other and the time series neural networks shows the best agreement with the experimental data.

CHAPTER 1

INTRODUCTION

1.1 Research background

Ceramics materials can be defined as “Any inorganic and non-metallic product prepared by treatment at temperatures higher than 540°C (1,000°F) or used under conditions implying these temperatures, which includes metallic oxides and borides, carbides, nitrides and mixtures of these compounds” (Boch & Niepce, 2010). Ceramic materials have interesting properties, including refractoriness, high melting point, high strength at high temperature, and applicable mechanical properties (compressive strength, hardness, erosion resistance, wear resistance). In the light of these attractive combination of properties, ceramics material has high potential to be candidate in many different application. However these comprehensive application are limited because of the brittleness and variability in mechanical properties.

Ceramic materials are mainly used in six main applications i.e. bioceramic, armor and military, wear and erosion, cutting tools, energy and high temperature and aircraft and aerospace equipment (Rosso, 2006). Figure 1-1 shows the value of these application in the North America market. Bioceramic become the biggest segment of the ceramic applications followed by armor and military application (Wellesley, 2012).

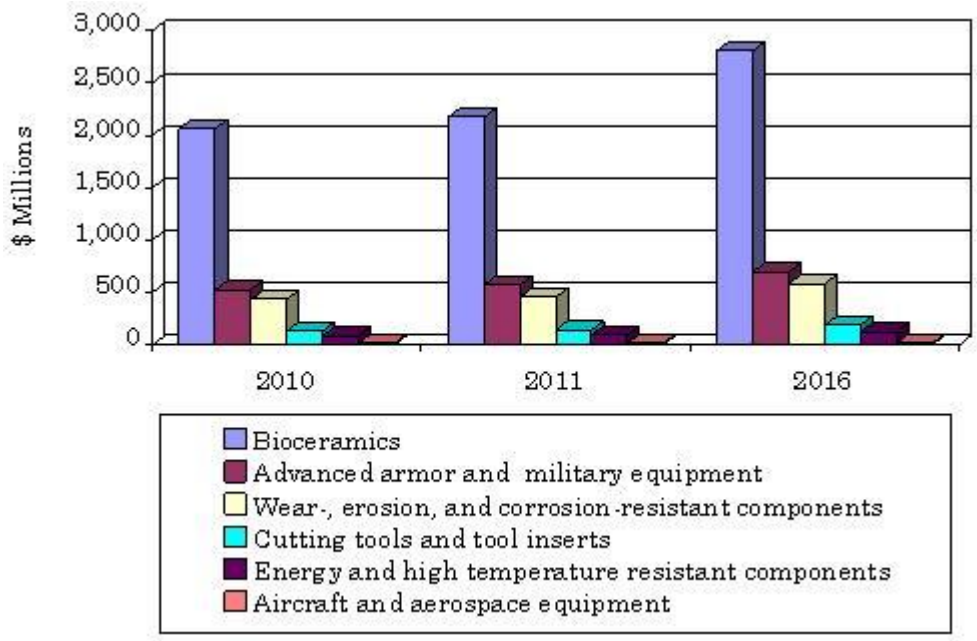

Figure 1-1 North American technical and advanced structural ceramics marketed based on applications (Wellesley, 2012)

History shows that the armors developed in parallel with the development of weapons. There are many different materials used for the armor application. One of the first recorded example of the use of body armors was by the medieval Japanese who used armor manufactured from silk to withstand from arrow penetration (Turnbull, 2012). Later with the progress in the weaponry technology, metals were used as an armor. But modern projectiles are able to penetrate the metal armors, thus the armor designer are looking for new materials that can stand against modern projectiles. Ceramic is a good candidate for armor. The ceramic usage as armor has started after WWII. This application was extended when the ceramic armor save the life of the many helicopter's pilot during the Vietnam War (Walley, 2010).

Ceramics offer many attractive properties for armor application, such as high specific stiffness, high specific strength, low thermal conductivity, and chemical inertness in various environments. The unique combination of low density (lightweight), superior hardness and high compressive strength compared to metals