UNIVERSITI PUTRA MALAYSIA

SYNTHESIS AND CHARACTERIZATION OF CARBON NANOTUBES AND NANO ALUMINA-REINFORCED ALUMINUM MATRIX NANOCOMPOSITES

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By

MEYSAM TOOZANDEHJANI

Thesis submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

December 2017

DEDICATION

to

My Parents

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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Chair : Assoc. Prof. Khamirul Amin Matori, PhD
Faculty : Institute of Advanced Technology

Owing to the unique properties of carbon nanotubes (CNTs) and alumina (Al_2O_3) nanoparticles, they have been incorporated into aluminum matrix as the reinforcement to fabricate light-weight Al-Al_2O_3 and Al-CNTs nanocomposites. Al-Al_2O_3 and Al-CNTs have been widely used in different applications in aerospace, automotive and military industries due to excellent combination of properties including high strength, high stiffness and good wear resistance as well as improved thermal and electrical properties. Addition of even small amount of these nanoparticles provides effective improvement of the overall physical and mechanical behaviour of nanocomposites. However, incorporating of CNTs and Al_2O_3 nanoparticles into aluminum matrix is difficult task particularly when larger contents of these nanoparticles are used.

The aim of this research was to investigate the feasibility of synthesizing of Al-Al_2O_3 and Al-CNTs as well as hybrid Al-CNTs-Al_2O_3 nanocomposites by using a combination of mechanical ball milling and powder metallurgy route. The effect of hybridization of Al matrix by the addition of both CNTs and Al_2O_3 nanoparticles on morphology and microstructural features and subsequent effect on physical and mechanical behavior of hybridized nanocomposites was investigated and compared with single-reinforced Al-CNTs and Al-Al_2O_3 nanocomposites. Finally, the applicability of ultrasonic non-destructive evaluation technique for characterization of the microstructure and mechanical properties of all nanocomposites was studied.

To achieve the proposed research objectives, all nanocomposites were synthesized using a combination of ball milling and powder metallurgy route. Ball milling at different times was employed to disperse different contents of CNTs and Al_2O_3 nanoparticles within aluminum powder. Nanocomposite powders were then consolidated by compaction at 150 MPa followed by sintering at 530 °C. Structural and microstructural features were characterized as a function of milling time and

nanoparticles contents using SEM, FESEM, TEM, HRTEM, particle size analyzer, XRD and Raman spectroscopy. Physical and mechanical behavior of nanocomposites was characterized using density, hardness, compression and nanoindentation tests. Ultrasonic measurements were carried out to measure ultrasonic parameters; ultrasonic velocity and attenuation in order to establish a correlation between ultrasonic parameters and structural, microstructural and physical and mechanical properties of these nanocomposites.

The results revealed that designated ball milling contributes to a homogenous dispersion of different amount of CNTs and Al_2O_3 nanoparticles, reduction of particle clustering, reduction of inter-particle spacing, reduction in particle size and grain refining. However, designated ball milling was found to be not efficient in dispersion of CNTs content more than 2 wt.% while it was efficient in dispersion of different amount of Al_2O_3 up to 10 wt.%. These morphological and microstructural variations within milling process significantly affect the physical and mechanical behaviour of Al-CNTs and Al-Al_2O_3 nanocomposites. Most interestingly, hybridization of Al-CNTs-Al_2O_3 nanocomposites exerts better physical and mechanical properties as compared to Al-CNTs and Al-Al_2O_3 nanocomposites. It was found that micro-hardness, nano-hardness and Young's modulus of Al-2CNTs-Al_2O_3 nanocomposites significantly increases by increasing Al_2O_3 content by 35%, 30 % and 38%, respectively. Further, ultrasonic measurement revealed a good correlation between ultrasonic parameters with microstructural features and mechanical properties induced by ball milling and further powder metallurgy route.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

SINTESIS DAN PENCIRIAN MATRIK ALUMINUM KOMPOSIT DIPERKUATKAN DENGAN TIUB NANO KARBON DAN NANO ALUMINA

Oleh

MEYSAM TOOZANDEHJANI

Disember 2017

Pengerusi : Prof Madya Dr Khamirul Amin Matori, PhD
Faculti : Institut Teknologi Maju

Disebabkan oleh keunikan sifat-sifat yang terdapat pada CNTs dan Al_2O_3 nanopartikel, kedua-duanya telah digabungkan ke dalam matrik aluminium sebagai bahan pengukuh untuk menghasilkan Al-Al_2O_3 dan Al-CNTs nanokomposit yang ringan. Al-Al_2O_3 dan Al-CNTs telah digunakan secara meluas di pelbagai aplikasi dalam industri aeroangkasa, automotif dan ketenteraan kerana kombinasi ciri-ciri yang sangat baik termasuk kekuatan tinggi, kekukuhan tinggi dan rintangan haus yang baik serta dapat meningkatkan sifat terma dan elektrik. Penambahan walaupun sedikit nanopartikel ini memberikan peningkatan yang berkesan terhadap tingkah laku fizikal dan mekanikal nanokomposit. Walau bagaimanapun, penggabungan CNTs dan Al_2O_3 nanopartikel ke dalam matriks aluminium adalah sesuatu yang sukar terutamanya apabila kandungan nanopartikel yang digunakan adalah lebih besar.

Tujuan penyelidikan ini adalah untuk mengkaji kebolehlaksanaan sintesis Al-Al_2O_3 dan Al-CNTs serta hibrid Al-CNTs-Al_2O_3 nanokomposit dengan menggunakan kombinasi kaedah pengisaran bebola mekanikal dan metalurgi serbuk. Kesan hibridisasi Al matriks dengan penambahan kedua-dua CNT dan nanopartikel Al_2O_3 pada morfologi dan ciri-ciri mikrostruktur serta kesan selanjutnya terhadap tingkah laku fizikal dan mekanik nanokomposit hibrid telah dikaji dan dibandingkan dengan Al-CNTs dan Al-Al_2O_3 nanokomposit bahan pengukuh tunggal. Akhir sekali, kebolehgunaan ultrasonik sebagai teknik penilaian yang tidak merosakkan untuk pencirian mikrostruktur dan sifat-sifat mekanik semua nanocomposites telah dikaji.

Untuk mencapai matlamat penyelidikan yang dicadangkan, nanokomposit disintesis menggunakan teknik gabungan pengisaran bebola mekanikal dan metalurgi serbuk. Teknik pengisaran bebola mekanikal dengan perbezaan masa yang berlainan digunakan untuk menyebarkan CNTs dan Al_2O_3 nanopartikel yang berbeza kandungan ke dalam serbuk aluminium. Serbuk nanokomposit ini kemudiannya dibentuk dengan proses

pemadatan pada tekanan 150 MPa dan diikuti dengan proses pensinteran pada 530 °C. Ciri-ciri struktur dan mikrostruktur diukur merujuk kepada perbezaan masa pengisaran dan kandungan nanopartikel dengan menggunakan SEM, FESEM, TEM, HRTEM, penganalisis saiz zarah, XRD dan Raman spektroskopi. Ciri-ciri fizikal dan mekanik nanokomposit dianalisis merujuk dengan menggunakan ujikaji ketumpatan, kekerasan, ujian mampatan dan ujian nanoindentasi. Analisis ultrasonik digunakan untuk mengukur parameter ultrasonik; halaju dan pelemahan ultrasonik untuk membentuk hubungan antara parameter ultrasonik dan tingkah laku struktur mikrostruktural dan fizikal nanokomposit.

Keputusan kajian menunjukkan bahawa pengilangan bola yang ditetapkan secara amnya menyumbang kepada penyebaran homogen nanopartikel CNTs dan Al_2O_3 dalam jumlah yang berbeza, pengurangan pengelompokan zarah, pengurangan jarak antar partikel antara zarah, pengurangan saiz zarah dan penghalusan butiran. Walau bagaimanapun, pengisaran bola yang ditetapkan adalah tidak berkesan untuk penyebaran kandungan CNTs yang lebih daripada 2% tetapi ianya lebih efisien dengan penyebaran sehingga 10% berat Al_2O_3. Variasi morfologi dan mikrostruktur dengan menggunakan proses ini telah meningkatkan keupayaan fizikal dan mekanikal kedua-dua Al-CNTs dan Al-Al_2O_3 nanokomposit. Paling menarik, Al-CNTs-Al_2O_3 hibrid nanokomposit telah menunjukkan ciri-ciri mekanikal yang lebih baik berbanding dengan Al-CNTs dan Al-Al_2O_3 nanokomposit. Telah didapati bahawa kekerasan mikro, kekerasan nano dan modulus Young daripada Al-2CNTs-Al_2O_3 nanokomposit meningkat dengan ketara dengan meningkatkan kandungan Al_2O_3 sebanyak 35%, 30% dan 38%. Selanjutnya, pengukuran ultrasonik menunjukkan korelasi yang baik antara parameter ultrasonik dengan ciri-ciri mikrostruktur dan sifat-sifat mekanikal yang disebabkan oleh teknik pengisaran bebola mekanikal dan metalurgi serbuk.

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I certify that a Thesis Examination Committee has met on 29 DEC 2017 to conduct the final examination of MEYSAM TOOZANDEHJANI on his thesis entitled "Synthesis and characterization of carbon nanotubes and nano alumina-reinforced aluminum matrix nanocomposites" in accordance with the Universities and Universiti College Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The committee recommends that the student be awarded the doctor of philosophy. Members of the Thesis Examination Committee were as follows:

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBRAVIATIONS

Al	Aluminum
MMCs	Metal Matrix Composites
AMCs	Aluminum Matrix Composites
CNTs	Carbon Nanotubes
PM	Powder Metallurgy
NDEs	Nondestructive Evaluation Techniques
MWCNTs	Multi-walled Carbon Nanotubes
SWCNTs	Single-walled Nanotubes
EDX	Energy-dispersive X-Ray Spectrometer
Al_2O_3	Alumina
SEM	Scanning Electron Microscopy
TEM	Transmission Electron Microscopy
HRTEM	High-resolution Transmission Electron Microscopy
XRD	X-Ray Diffraction
FESEM	Field Emission Scanning Electron Microscopy
PDC	Physical Dimensional Changes
CVD	Chemical Vapor Deposition

CHAPTER 1

INTRODUCTION

1.1 Introduction

In various industrial applications, aluminum (Al) and its alloys as a lightweight alloy are being replacing by aluminum matrix composites (MMCs) to achieve lightweight, high performance, and environmental friendly materials as well as energy saving (Miracle, 2005; Rohatgi and Schultz, 2007; Everett and Arsenault, 1991). Aluminum matrix composites (AMCs) are widely employed in different applications such as aerospace, automotive and military industries. The main reason behind the wide application of AMCs is their excellent combination of properties as compared to the unreinforced aluminum alloys. Those properties are high strength and stiffness, good wear resistance and improved thermal and electrical properties. In addition, the main contribution of AMCs in engineering applications is the weight reduction which exerts energy saving along with a reduction in the cost (Surappa, 2003; Kaczmar et al., 2000; Davis, 1999).

Like other MMCs, the properties of AMCs is closely associated to the reinforcement (its amount and type) and synthesizing processing of the composite (Rohatgi and Schultz, 2007; Casati and Vedani, 2014; Kaczmar, et al., 2000). A wide variety of reinforcements have been used to reinforce aluminum matrix such as SiC, B_4C, Al_2O_3, AlN, Si_3N_4, TiC, TiO_2, TiB_2 in different type, shape, and sizes. The most widely used reinforcements are SiC, Al_2O_3 and graphite in the form of particles or whiskers due to high availability, low cost and overall good properties (Wessel, 2004; Casati and Vedani, 2014). Carbon nanotubes (CNTs) have also gained interest among researchers as a reinforcement material for fabrication of novel AMCs (Salvetat et al., 1999; Bakshi and Agarwal, 2011; Bradbury, 2014; Esawi et al., 2010; Popov, 2004).

Different techniques have been employed to manufacture AMCs including liquid state and solid state techniques. It is well known that different manufacturing techniques, the processing and the finishing, and also different reinforcements provide various characteristic profiles while the same composition and amounts of components are used (Uozumi et al., 2008). Among available techniques, powder metallurgy (PM) has shown its potential in the field as the most feasible and economical method for manufacturing AMCs. PM composites are increasingly used in aerospace and automotive industries due to the improved properties owing to the ability of PM process to provide uniform dispersion of reinforcement (Srivatsan et al., 1991; Torralba et al., 2003; O'Donnel and Looney, 2001). In fact, reinforcing aluminum matrix particularly with those in nano-sized range, necessitate a proper technique to yield a uniform dispersion of reinforcements. Mechanical milling process has found to be effective in homogeneous dispersion of reinforcements in the Al matrix along with refinement of the microstructure (Toozandehjani et al., 2017; Ostovan, Matori and Toozandehjani et al., 2016; Suryanarayana, 2001). Mechanical milling through ball milling provides better homogeneous dispersion of the reinforcement particles within the aluminum matrix which avoids the segregation and agglomeration of the reinforcement particles (Razavi Hesabi et al., 2007; Esawi and Morsi, 2007; Ostovan, Matori and Toozandehjani et al., 2015; Fogagnolo, Velasco, et al., 2003; Toozandehjani et al., 2017).

Non-destructive evaluation techniques (NDEs) have been introduced to the MMCs (Mott and Liaw, 1988; Liaw et al., 1992; Liaw et al., 1994; Lu and Liaw, 1995; Gür and Ogel, 2001; El-Daly et al., 2010). NDEs are generally used for defect detection and characterization in the component. However, NDEs have also shown their potential in characterization of microstructure and mechanical properties of materials. Ultrasonic technique is considered to be the most practically feasible technique for evaluation of microstructure and mechanical properties of alloys (Toozandehjani, Matori, et al., 2015). The ultrasonic parameters; velocity and attenuation provide information about the structural and geometrical parameters of the material which can be used for the analysis and design of AMCs. It has been proven that indirect assessment of the microstructure and mechanical properties of AMCs by measurement of ultrasonic parameters is possible (Toozandehjani, Matori, et al., 2015).

1.2 Problem Statement

Owing to the unique properties of CNTs and Al_2O_3 nanoparticles, they have incorporated into the aluminum matrix as a reinforcement to fabricate alumina reinforced aluminum matrix composites (Al-Al_2O_3) and carbon nanotubes reinforced aluminum matrix composites (Al-CNTs). Addition of even small amount of these nanoparticle reinforcements provides an effective improvement of the physical and mechanical behavior of these nanocomposites. Incorporating CNTs and Al_2O_3 nanoparticles into the aluminum matrix is difficult task particularly when a larger content of these nanoparticles is used (Ostovan, 2015). As a matter of fact, dispersion technique of CNTs and Al_2O_3 into aluminum matrix affects the degree of dispersion CNTs and Al_2O_3 nanoparticles, interfacial features of constituent and consequently physical and mechanical behavior of nanocomposites. It might even decrease the mechanical properties of aluminum (Estruga et al., 2013; Suryanarayana and Al-Aqeeli, 2013; Uozumi et al., 2008). Clustering of reinforcements is a challenging issue in aluminum composites. In particular case of hybrid nanocomposites, simultaneous incorporation of two different nanoparticle reinforcements and their dispersion seems to be more difficult since Al_2O_3 and CNTs nanoparticles are different in nature, one sphere shape and one fibrous (nanotubes shape). A review of the existed literature revealed that only limited studies have been carried out on the intrinsic effect of the hybridization of aluminum using Al_2O_3 and CNTs nanoparticles by adopting a combination of ball milling and powder metallurgy processing route. Due to the technological interest of ball milling, the effect of ball milling time on the dispersion of Al_2O_3 and CNTs nanoparticles in hybridized Al-CNTs-Al_2O_3 nanocomposites is not fully investigated.

In addition, different characterization techniques have been employed to investigate the effect of the addition of CNT and Al_2O_3 nanoparticles into Al matrix and synthesizing process parameters on the final properties of nanocomposites. Recently, ultrasonic characterization is of interest of researchers for evaluation of properties of MMCs since ultrasonic wave parameters; velocity and attenuation are functionally related to structural and microstructural features of MMCs. Although, some works have been done on the ultrasonic characterization of AMCs (Gür and Ogel, 2001; El-Daly et al., 2010; El-Daly et al., 2013), but the ultrasonic characterization of Al-CNTs, Al-Al_2O_3 and hybrid Al-CNTs-Al_2O_3 nanocomposites has not been reported as far as deduced from the literature. There is still a high necessity to study in depth the effect of nanoparticle reinforcement and processing parameters on the ultrasonic properties of these nanocomposites. In addition, the effect of CNTs and Al_2O_3 content and their dispersion state on ultrasonic parameters; velocity and attenuation are not fully studied yet. It is a well-known fact that the amount and dispersion of the nanoparticle reinforcements considerably influence the microstructure and mechanical properties of AMCs. Therefore, monitoring such variation with the help of nondestructive methods would be useful.

For the above-mentioned reasons, an experimental work was carried out in order to investigate the feasibility of synthesizing Al-CNTs and Al-Al_2O_3 as well as hybridized Al-CNTs-Al_2O_3 nanocomposite by a combination of ball milling and powder metallurgy route. The effect of the addition of CNTs and Al_2O_3 nanoparticles and processing parameters on the morphological and microstructural features and subsequent effect on the physical and mechanical behavior of Al-CNTs, Al-Al_2O_3, and hybridized Al-CNTs-Al_2O_3 nanocomposite is investigated. Additionally, the effect of hybridization of the aluminum matrix by the addition of CNT and Al_2O_3 nanoparticles is compared with those of single reinforced Al-CNTs and Al-Al_2O_3 nanocomposites. In addition, ultrasonic characterization has been used to characterize the synthesized nanocomposites in order to establish a correlation between microstructural features of nanocomposites and ultrasonic parameters; ultrasonic wave velocity and ultrasonic wave attenuation.

1.3 Hypothesis

The hypothesis may include the following:

1. Mechanical alloying through ball milling as a part of powder metallurgy route is a suitable for synthesizing of Al-CNTs and Al-Al_2O_3 nanocomposites since it provides a good dispersion of CNTs and Al_2O_3 nanoparticles and probably a combination of both reinforcements.
2. CNTs and Al_2O_3 nanoparticle reinforcements significantly improve the mechanical properties of the pure aluminum matrix.
3. Hybridization of aluminum matrix contributes to the further enhancements of mechanical properties compared to the single reinforced nanocomposites.
4. The microstructural and morphological variation within ball milling of Al-CNTs and Al-Al_2O_3 nanocomposites are correlated to the ultrasonic parameters.

1.4 Objectives

This study embarks on the following specific objectives:

1. To study the feasibility of synthesizing Al-CNTs and Al-Al_2O_3 as well as hybrid Al-CNTs-Al_2O_3 nanocomposite using a combination of mechanical ball milling and powder metallurgy.
2. To investigate the effect of addition of CNTs and Al_2O_3 nanoparticles and milling time on morphology, microstructure features and subsequent effect on the physical and mechanical behavior of Al-CNTs and Al-Al_2O_3 nanocomposites.
3. To explore the effect of hybridization of Al matrix by simultaneous addition of both CNTs and Al_2O_3 nanoparticles on morphology, microstructure features and subsequent effect on the physical and mechanical behavior of hybrid Al-CNTs-Al_2O_3 nanocomposites compared with those of single reinforced Al-CNTs and Al-Al_2O_3 nanocomposites.
4. To illustrate the applicability of ultrasonic techniques in characterization of the morphological, microstructural, physical and mechanical behavior of Al-CNTs and Al-Al_2O_3 nanocomposites as well as hybridize Al-CNTs-Al_2O_3 nanocomposites.

REFERENCES

Adamiak, M., Fogagnolo, J. B., Ruiz-Navas, E. M., Dobrzañski, L. A. and Torralba, J. M. (2004). Mechanically milled AA6061/(Ti_3Al) PMMC reinforced with intermetallics-the structure and properties. *Journal of Materials Processing Technology*, 155: 2002-2006.

Aghaie-Khafri, M., Honarvar, F. and Zanganeh, S. (2012). Characterization of grain size and yield strength in AISI 301 stainless steel using ultrasonic attenuation measurements. *Journal of Nondestructive Evaluation.* 31:191-196.

Ahamed, H. and Senthilkumar, V. (2010). Role of nano-size reinforcement and milling on the synthesis of nano-crystalline aluminium alloy composites by mechanical alloying. *Journal of Alloys and Compounds*, 505: 772-782.

Ahn, J. H., Kim, Y. J. and Yang, S. S. (2013). Multiwall carbon nanotube reinforced aluminum matrix composites prepared by ball milling. *Applied Mechanics and Materials*, 372: 119-122.

Akbarpour, M. R., Salahi, E., Alikhani Hesari, F., Simchi, A. and Kim, H. S. (2013). Fabrication, characterization and mechanical properties of hybrid composites of copper using the nanoparticulates of SiC and carbon nanotubes, Material Science and Engineering A, 572: 83–90.

Al-Aqeeli, N., Abdullahi, K., Suryanarayana, C., Laoui, T. and Nouari, S. (2012). Structure of mechanically milled CNT-reinforced Al-alloy nanocomposites. *Materials and Manufacturing Processes*, 28: 984-990.

Alhashmi, H. (2012). *Fabrication of aluminium matrix composites (AMCs) by squeeze casting technique using carbon fiber as reinforcement*. Master Thesis. University of Ottawa, Canada.

Alizadeh, M. and Mirzaei Aliabadi, M. (2011). Synthesis behavior of nanocrystallineAl–Al_2O_3 composite during low time mechanical milling process. *Journal of Alloys and Compound*, 509: 4978–4986.

Aqida, S. N., Ghazali, M. I., Hashim, J. (2004). Effects of porosity on mechanical properties of metal matrix composite: An Overview. *Jurnal Teknologi*, 40: 17-32.

Arsenault, R. J. and Pande, C. S. (1984). Interfaces in metal matrix composites. Scripta Metallugica, 18: 1131-1134.

Arzt, E. and Schultz, L. (1989). New Materials by Mechanical Alloying Techniques. *Material and Manufacturing Process*, 6: 733-736.

ASM International. (1998). *ASM handbook: Powder Metal Technologies and Applications: Volume 7*. Materials Park, OH: ASM International.

ASTM B417-13. (2013). *Standard test method for apparent density of non-free-flowing metal powders using the carney funnel*. ASTM International, West Conshohocken, PA, www.astm.org.

ASTM B610-13. (2013). *Standard test method for measuring dimensional changes associated with processing metal powders*. ASTM International. West Conshohocken, PA, www.astm.org.

ASTM B962-08. (2008). *Standard test methods for density of compacted or sintered powder metallurgy (pm) products using archimedes' principle*. ASTM International. West Conshohocken, PA, www.astm.org.

ASTM E 494-05. (2005). *Standard practice for measuring ultrasonic velocity in materials*. ASTM International. West Conshohocken, PA, www.astm.org.

Auld, B. A. and Moulder, J. C. (1999). Review of advances in quantitative eddy current nondestructive evaluation, *Journal of Nondestructructive Evalaluation*, 18: 3-35.

Ausman, K. D., Piner, R., Lourie, O., Ruoff, R. S. and Korobov, M. (2000). Organic solvent dispersions of single-walled carbon nanotubes: toward solutions of pristine nanotubes. *The Journal of Physical Chemistry B*, 104: 8911-8915.

Awal, M.A. (1995). *Low frequency acoustic microscopy for material characterization.* Phd Thesis, University of Arizona, USA.

Badidi Bouda, A., Benchaala, A. and Alem, K. (2000). Ultrasonic characterization of materials hardness. *Ultrasonics.* 38:224–227.

Bakker, H., Zhou, G. F. and Yang, H. (1995). Mechanically driven disorder and phase transformations in alloys. *Progress in materials science*, 39: 159-241.

Bakshi, S. R. and Agarwal, A. (2011). An analysis of the factors affecting strengthening in carbon nanotube reinforced aluminum composites. *Carbon*, 49: 533-544.

Bakshi, S. R., Lahiri, D. and Agarwal, A. (2010). Carbon nanotube reinforced metal matrix composites-a review. *International Materials Reviews*, 55: 41-64.

Bakshi, S. R., Singh, V., Balani, K., McCartney, D. G., Seal. And Agarwal, A. (2008). Carbon nanotube reinforced aluminum composite coating via cold spraying. *Surface and Coatings Technology*, 202: 5162-5169.

Baqeri, R., Honarvar, F. and Mehdizad, R. (2012). *Case depth profile measurement of hardened components using ultrasonic backscattering method*. 18th world conference on nondestructive testing, South Africa.

Baradeswaran, A. and Elaya Perumal, A. (2014). Study on mechanical and wear properties of Al 7075/Al_2O_3/graphite hybrid composites, Composites: B. 56: 464-471.

Basariya, M. R., Srivastava, V. C. and Mukhopadhyay, N. K. (2014). Microstructural characteristics and mechanical properties of carbon nanotube reinforced aluminum alloy composites produced by ball milling. Materials and Design, 64: 542-549.

Bauman, I., Ćurić, D. and M. Boban. (2008). Mixing of solids in different mixing devices. *Sadhana*, 33: 721–731.

Bayraktar, E., Masounave, J., Caplain, R. and Bathias, C. (2008). Manufacturing and damage mechanisms in metal matrix composites. *Journal of Achievements in Materialsand Manufacturing Engineering*, 31-294-300.

Benjamin, J. S. (1970). Dispersion strengthened superalloys by mechanical alloying. *Metallurgical transactions*, 1: 2943-2951.

Benjamin, J. S. and Bomford, M. J. (1977). Dispersion strengthened aluminum made by mechanical alloying. *Metallurgical Transactions A*, 8: 1301-1305.

Brown, L. M. and Ham, R. K. (1971). *Strengthening methods in crystals*. Elsevier, Amsterdam. 9–135.

Bindumadhavan P. N., Heng K. W. and Prabhakar, O. (2002). Assessment of particle–matrix debonding in particulate metal matrix composites using ultrasonic velocity measurements. *Materials Science and Engineering A*, 323: 42–51.

Blitz, J. and G. Simpson. (1996). *Ultrasonic methods of non-destructive testing*. Chapman and Hall, London.

Boch, P. and Niepce, J. C. (2007). *Ceramic Materials: Processes, Properties and Applications.* ISTE Ltd. UK.

Bockstiegel, G. (2003). Production of Sintered Components. *Höganäs Handbook for Sintered Components*. Höganäs AB, Sweden.

Bottiglieri, S. (2012). *The effect of microstructure in aluminum oxide ceramics on acoustic loss mechanisms*. PhD Dissertation. Rutgers University–New Brunswick. USA.

Botvina, L. R., Fradkin, L. J. and Bridge, B. (2000). A new method for assessing the mean grain size of polycrystalline materials using ultrasonic NDE. *Journal of Material Science*. 35:4673-4683.

Bradbury, C. R., Gomon, J., Kollo, L., Kwon, H. and Leparoux, M. (2014). Hardness of multi wall carbon nanotubes reinforced aluminummatrix composites, *Journal of Alloys and Compound*, 585: 362-367.

Bright, I., Koutsos, V., Li, Q. and Cheung, R. (2006). Carbon nanotubes for integration into nanocomposite materials. *Microelectronic engineering*, 83: 1542-1546.

Cahn, R. W., Haasen, P. and Kramer, E. J. (1991). *Materials Science and Technology-A Comprehensive Treatment*, Wiley-VCH, Weinheim, New York, USA.

Callister, W. D. (2001). *Fundamentals of materials science and engineering: an interactive e.Text*. 5th Vol. New York. Wiley.

Campbell, F. C. (2006). Aluminum. In *Manufacturing technology for aerospace structural materials*. Campbell, F.C., Elsevier Ltd.

Campbell, F. C. (2003). *Manufacturing Processes for Advanced Composites*. Elsevier, Oxford.

Carter, B. and Norton, M. G. (2007). *Ceramic Materials: Science and Engineering*. Springer-Verlag, New York. USA.

Casiraghi, C., Ferrari, A. C., and Robertson, J. (2005). Raman spectroscopy of hydrogenated amorphous carbons. *Physical Review B*, 72: 085401-14.

Casati, R. and Vedani, M. (2014). Metal matrix composites reinforced by nanoparticles- a review, *Metals*, 4: 65-83.

Casati, R., Wei, X., Xia, K., Dellasega, D., Tuissi, A., Villa, E. nd Vedani, M. (2014). Mechanical and functional properties of ultrafine grained Al wires reinforced by nano-Al_2O_3 particles. *Materials & Design*, *64*: 102-109.

Chang, L. S., Chuang, T. H. and Wei, W. J. (2000). Characterization of alumina ceramics by ultrasonic testing. *Materials Characterizaiton*, 45: 221-226.

Chawla, K. K. (1992). Composite materials science and engineering. New York, Springer-Verlag.

Chawla, N. and Chawla, K. K. (2006). Metal matrix composites. New York, Springer.

Chawla, K. K. (1995). The high-temperature application of ceramic-matrix composites. *Journal of Minerals,Metals and Materials Society (TMS)*, 47: 19-21.

Chawla, N. and Shen Y. L. (2001). Mechanical behavior of particle reinforced metal matrix composites. *Advanced Engineering Materials*, 3: 357-370.

Chen, L. Y., Peng, J. Y., Xu, J. Q., Choi, H. and Li, X. C. (2013). Achieving uniform distribution and dispersion of a high percentage of nanoparticles in metal matrix nanocomposites by solidification processing. *Scripta Materialia*, 69: 634-637.

Chen, X. H., Chen, C. S., Xiao, H. N., Chen, X. H., Li, W. H. and Xu, L. S. (2005). Lipophilic functionalization of multi-walled carbon nanotubes with stearic acid. *Carbon*, 43: 1800-1803.

Cho, J. and Daniel, I. M. (2008). Reinforcement of carbon/epoxy composites with multi-wall carbon nanotubes and dispersion enhancing block copolymers. *Scripta Materialia*, 58: 533-536.

Christensen, R. M. (2012). *Mechanics of composite materials*. Courier Corporation, Massachusetts, USA.

Ci, L., Ryu, Z., Jin-Phillipp, N. Y. and Rühle, M. (2006). Investigation of the interfacial reaction between multi-walled carbon nanotubes and aluminum. *Acta Materialia*, 54: 5367-5375.

Clyne, T. W. and Withers, P. J. (1993). *An introduction to metal matrix composites*. Cambridge University Press, Cambridge, UK.

Collins, D. N. and Alcheikh, W. (1995). Ultrasonic non-destructive evaluation of the matrix and the graphite shape in cast iron. *Journal of Materials Processing Technology*, 55: 85-90.

Cyriac, A. J. (2011). Metal Matrix Composites: History, Status, Factors and Future. Master Thesis. Cochin University of Science and Technology, INDIA.

Da Rocha, C. J., Neto, R. M. L., Gonçalves, V. S., Carvalho, L. L. and Ambrozio Filho, F. (2003). An investigation of the use of stearic acid as a process control agent in high energy ball milling of Nb-Al and Ni-Al powder mixtures. *Materials science forum*, 416: 144-149.

Davis, J. R. (1993). *Aluminum and aluminum alloys*. ASM Specialty Handbook, ASM International. Metal Parts. Ohio, USA.

Delebarre, C., Baquett, I., Bruneel, C., Rouvaen, J. M. and Z. Derouiche. (1992). Quantitative characterization of metal matrix composites using histogram processing techniques. *NDT&E International*, 25: 195-200.

Demczyk, B. G. Wang, Y. M., Cumings, J., Hetman, M., Han, W., Zettl, A. and Ritchie, R. O. (2002). Direct mechanical measurement of the tensile strength and elastic modulus of multiwalled carbon nanotubes. *Materials Science and Engineering A*, 334: 173-178.

Deng, C. F., Wang, D. Z., Zhang, X. X. and Li, A. B. (2007). Processing and properties of carbon nanotubes reinforced aluminum composites. *Materials Science and Engineering: A*, 444: 138-145.

Devaraju, A., Kumar, A. and Kotiveerachari, B. (2013). Influence of addition of Gr_p/Al_2O_3p with SiC_p on wear properties of aluminum alloy 6061-T6 hybrid composites via friction stir processing. *Transactions of Nonferrous Metals Society of China*, 23: 1275−1280.

Devaraju, A., Kumar, A., Kumaraswamy, A. and Kotiveerachari, B. (2013). Influence of reinforcements (SiC and Al_2O_3) and rotational speed on wear and mechanical properties of aluminum alloy 6061-T6 based surface hybrid composites produced via friction stir processing. *Materials and Design*, 51: 331–341.

Dowson, G. (1990). *Powder metallurgy: the process and its products*. Springer, Amesterdam, Netherlands.

Dubois, M., Militzer, M., Moreau, A. and Bussière, J. F. (2000). A new technique for the quantitative real-time monitoring of austenite grain growth in steel. *Scripta Materialia*, 42: 867–874.

Dumonteil, S., Demortier, A., Detriche, S., Raes, C., Fonseca, A., Rühle, M. and Nagy, J. B. (2006). Dispersion of carbon nanotubes using organic solvents. *Journal of nanoscience and nanotechnology*, 6: 1315-1318.

El-Daly, A. A., Abdelhameed, M., Hashish, M. and Daoush, W. M. (2013). Fabrication of silicon carbide reinforced aluminum matrix nanocomposites and characterization of its mechanical properties using non-destructive technique, Materials Science and Engineering A, 559: 384-393.

El-Daly, A. A., Abdelhameed, M., Hashish, M. and Eid, A. M. (2012). Synthesis of Al/SiC nanocomposite and evaluation of its mechanical properties using pulse echo overlap method, *Journal of Alloys and Compounds*, 542: 51-58.

El-Daly, A. A. and Hammad, A. E. (2010). Elastic properties and thermal behavior of Sn–Zn based lead-free solder alloys. *Journal of Alloys and Compounds*, 505: 793–800.

El-Daly, A. A., El-Tantawy, F., Hammad, A. E., Gaafar, M. S., El-Mossalamy, E. H. and Al-Ghamdi, A. A. (2011). Structural and elastic properties of eutectic Sn–Cu lead-free solder alloy containing small amount of Ag and In, *Journal of Alloys and Compounds*,509: 7238-7246.

Esawi, A. M. K. and El-Borady, M. A. (2008). Carbon nanotube-reinforced aluminium strips. *Composites Science and Technology*, 68: 486-492**.**

Esawi, A. M. K. and Morsi, K. (2007). Dispersion of carbon nanotubes (CNTs) in aluminum powder. *Composites Part A: Applied Science and Manufacturing*, 38: 646-650**.**

Esawi, A. M. K., Morsi, K., Sayed, A., Gawad, A. A. and Borah, P. (2009). Fabrication and properties of dispersed carbon nanotube–aluminum composites. *Materials Science and Engineering: A*, 508: 167-173.

Esawi, A .M. K., Morsi, K., Sayed, A., Taher, M. and Lanka, S. (2010). Effect of carbon nanotube (CNT) content on the mechanical properties of CNT-reinforced aluminum composites, *Composites Science and Technology*, 70: 2237-2241.

Esawi, A. M. K., Morsi, K., Sayed, A., Taher, M. and Lanka, S. (2011). The influence of carbon nanotube (CNT) morphology and diameter on the processing and properties of CNT-reinforced aluminium composites. *Composites Part A: Applied Science and Manufacturing*, 42: 234-243.

Estruga, M., Girard, S. N., Ding, Q., Chen, L., Li, X. and Jin, S. (2014). Facile and scalable synthesis of Ti_5Si_3 nanoparticles in molten salts for metal-matrix nanocomposites. *Chemical Communications*, 50: 1454-1457.

Estruga, M., Chen, L., Choi, H., Li, X. and Jin, S. (2013). Ultrasonic-assisted synthesis of surface-clean Tib_2 nanoparticles and their improved dispersion and capture in Al-matrix nanocomposites. *ACS applied materials & interfaces*, 5: 8813-8819.

Evans A., San Marchi, C. and Mortensen, A. (2003). *Metal Matrix Composites*. In: Metal Matrix Composites in Industry. Evans A., San Marchi C. and Mortensen A. Springer, Boston, USA**.**

Everett, R.K. and Arsenault, R. J. (1991) Metal Matrix Composites Mechanisms and Properties. Academic Press, San Diego, USA.

Fang, C. K., Fang, R. L., Weng, W. P. and Chuang, T. H. (1999). Applicability of ultrasonic testing for thedetermination of volume fraction of particulates in alumina-reinforced aluminum matrix composites. Materials Characterization, 43:217–226.

Fayed, M. E. and Otten. L. (1984). *Handbook of Powder Science and Technology*. Van Nostrand Reinhold Company Inc, New York, USA.

Fogagnolo, J. B., Ruiz, E. M., Robert, M. H. and Torralba, J. M. (2003). The effects of mechanical alloying on the compressibility of aluminium matrix composite powder. *Materials Science and Engineering: A*, 355: 50-55.

Fogagnolo, J. B., Velasco, F., Robert, M. H. and Torralba, J. M. (2003). Effect of mechanical alloying on the morphology, microstructure and properties of aluminium matrix composite powders. *Materials Science and Engineering: A*, 342: 131-143.

Freitas, V. L. A., Normando, P. G., Albuquerque, V. H. C., Silva, E., Silva, A. A. and Tavares, R.S. (2011). Nondestructive characterization and evaluation of embrittlement kinetics and elastic constants of duplex stainless steel SAF 2205 for different aging time at 425°C and 475 °C, *Journal of Nondestructructive Evaluation*. 30: 130-136.

Ganguli, A., Gao, R. X., Liang, K., Jundt, J. and Ordonez, A. (2010). Experimental investigation of ultrasound wave focusing in attenuative solids. IEEE Transactions on Instrumentation and Measurement, 59: 2261–2271.

García-Martín, J., Gómez-Gil, J. and Vázquez-Sánchez, E. (2011). Non-destructive techniques based on eddy current testing. *Sensors.* 11: 2525-2565.

Geim, A. K. and Kim, P. (2008). Carbon wonderland. *Scientific American*, 298: 90-97.

George, R., Kashyap, K. T., Murugesh, A. K. and Yamdagni, S. (2005). *Strengthening in aluminum-carbon nanotube composites*. International Conference on Nanomaterials: NANO 2005, Allied Publishers, 731-738.

George, R., Kashyap, K. T., Rahul, R. and Yamdagni, S. (2005). Strengthening in carbon nanotube/aluminium (CNT/Al) composites. *Scripta Materialia*, 53: 1159-1163.

German, R. M. (2003). Powder injection moulding, what the designer needs to know. *Metal Powder Report*, 58: 10-11.

German, R. M. (1984). *Powder metallurgy science*. Metal Powder Industries Federation, Princeton, NJ. USA.

German, R. M. (1996). *Sintering Theory and Practice*. Ed. Wiley-VCH, New York, USA.

Gowri Shankar, M. C., Jayashree, P. K. and Sharma, S. S. (2013). Individual and Combined Effect of Reinforcements on Stir Cast Aluminium Metal Matrix Composites. A Review, *International Journal of Current Engineering and Technology*, 3: 922-934.

Gür, C. H. and Ogel, B. (2001). Non-destructive microstructural characterization of aluminium matrix composites by ultrasonic techniques, Materials Characterization, 47: 227-233.

Hashmi, T. Q. (2015). Liquid state methods of producing metal matrix composites: A review article. *International Journal of Research in Mechanical Engineering & Technology*. 5:103-106.

Hassan, S. F. and Gupta, M. (2004). Development of high performance magnesium nanocomposites using solidification processing route. *Materials science and technology*, 20: 1383-1388.

He, C., Zhao, N., Shi, C., Du, X., Li, J., Li, H. and Cui, Q. (2007). An approach to obtaining homogeneously dispersed carbon nanotubes in Al powders for preparing reinforced Al-matrix composites, *Advanced Materials*, 19: 1128-1132.

He, C. N., Zhao, N. Q., Shi, C. S. and Song, S. Z. (2009). Mechanical properties and microstructures of carbon nanotube-reinforced Al matrix composite fabricated by in situ chemical vapor deposition. *Journal of Alloys and Compounds*, 487: 258-262.

Hellier, C. J. (2003). *Handbook of Nondestructive Evaluation*, Mc Graw-Hill, USA.

Hesabi, Z. R., Simchi, A. and Reihani, S. S. (2006). Structural evolution during mechanical milling of nanometric and micrometric Al_2O_3 reinforced Al matrix composites. *Materials Science and Engineering: A*, 428: 159-168.

Hull, D. and Clyne, T. W. (1996). *An introduction to composite materials*. Cambridge university press, UK.

Hwang, S., Nishimura, C. and McCormick, P. G. (2001). Mechanical milling of magnesium powders. *Materials Science and Engineering: A*, 318: 22-33.

Iijima, S. (1991). Helical microtubules of graphitic carbon. *Nature*, 354: 56-58.

Jafari, M., Abbasi, M. H., Enayati, M. H. and Karimzadeh, F. (2012). Mechanical properties of anostructured Al2024–MWCNT composite prepared by optimized mechanical milling and hot pressing methods. *Advanced Powder Technology*, 23: 205–210.

Jaykumar, T. and Mukhopadhyay, C. K. (2010). Non-destructive evaluation techniques for assessment of creep and fatigue damage in materials and components. *Transaction of Indian Institute of Metals*. 63: 301-311.

Jeong, H. (1998). Multiple NDE techniques for the measurement of constituent volume fractions in metal matrix composites. *Research in Nondestructive Evaluation*, 9: 41– 57.

Jeyasimman, D., Narayanasamy, R. and Ponalagusamy, R. (2015). Role of hybrid reinforcement on microstructural observation, characterization and consolidation behavior of AA6061 nanocomposite, *Advanced Powder Technology*, 26: 1171–1182.

Jeyasimman, D., Sivaprasad, K., Sivasankaran, S., Ponalagusamy, R., Narayanasamy, R and Vijayakumar Iyer (2015). Microstructural observation, consolidation and mechanical behaviour of AA6061 nanocomposites reinforced by γ-Al_2O_3 nanoparticles, Advanced Powder Technology, 26: 139-148.

Kaczmar, J., Pietrzak, K. and Włosiński, W. (2000). The production and application of metal matrix composite materials. *Journal of Materials Processing Technology*, 106: 58-67.

Kainer, K. U. (2006). *Metal matrix composites: custom-made materials for automotive and aerospace engineering*. Wiley-VCH, Weinheim, Germany.

Kang, Y. C. and Chan, S. L. I. (2004). Tensile properties of nanometric Al_2O_3 particulate-reinforced aluminum matrix composites. *Materials Chemistry and Physics*, 85: 438-443.

Kaplan, M., Gür, C.M. and Erdogan, M. (2007). Characterization of dual-phase steels using magnetic barkhausen noise technique. *Journal of Nondestructructive Evaluation*. 26: 79–87.

Karbalaei Akbari, M., Baharvandi, H. R. and Mirzaee, O. (2013). Fabrication of nano-sized Al_2O_3 reinforced casting aluminum composite focusing on preparation process of reinforcement powders and evaluation of its properties. *Composites: Part B*, 55: 426–432.

Kelly, A. (2006). Composite materials after seventy years. Journal of Materials Science, 41: 905–912.

Khakbiz, M. and Akhlaghi, F. J. (2009). Synthesis and structural characterization of Al-B_4C nanocomposite powders by mechanical alloying. *Journal of Alloys and Compounds*, 479: 334-341.

Khan, A. S., Farrokh, B. and Takacs, L. (2008). Effect of grain refinement on mechanical properties of ball-milled bulk aluminum. *Materials Science and Engineering: A*, 489: 77-84.

Kidd, T. H., Zhuang, S. and Ravichandran, G. (2007). An in-situ ultrasonic technique for simultaneous measurement of longitudinal and shear wave speeds in solids. *Experimental Mechanics*. 47:753–759.

Kim, H. H., Babu, J. S. S. and Kang, C. G. (2013). Fabrication of A356 aluminum alloy matrix composite with CNTs/Al_2O_3 hybrid reinforcements, *Materials Science and Engineering: A*, 573: 92–99.

Kim, H. S., Park, W. I., Kang, M. and Jin, H. J. (2008). Multiple light scattering measurement and stability analysis of aqueous carbon nanotube dispersions. *Journal of Physics and Chemistry of Solids*, 69: 1209-1212.

Kim, S. A. and Johnson, L. W. (2007). Elastic constants and internal friction of martensitic steel, ferritic-pearlitic steel, and α-iron. *Material Science and Engineering A*. 452–453:633–639.

Kim, W. J. and Yu, Y. J. (2014). The effect of the addition of multiwalled carbon nanotubes on the uniform distribution of TiC nanoparticles in aluminum nanocomposites, *Scripta Materialia*, 72–73: 25–28.

Kessler, M. R. (2012). Polymer matrix composites: A perspective for a special issue of polymer reviews. *Polymer Reviews*, 52: 229-233.

Koczak, M. J., Khatri, S. C., Allison, J. E., and Bader, M. G. (2013). *Metal-Matrix Composites for Ground Vehicle, Aerospace, and Industrial Applications*.

In Fundamentals of Metal-Matrix Composites, Elsevier Inc. Butterworth-Heinemann.
Koczak, M. J. and Premkumar, K. (1993). Emerging technologies for the in-situ production of MMCs. JOM, 45: 44–48.
Koch, C. C., Cavin, O. B., McKamey, C. G. and Scarbrough, J. O. (1983). Preparation of amorphous Ni60Nb40 by mechanical alloying. *Applied physics letters*, 43: 1017-1019.
Kök, M. (2006). Abrasive wear of Al_2O_3 particle reinforced 2024 aluminium alloy composites fabricated by vortex method. *Composites Part A: Applied Science and Manufacturing*, 37: 457-464.
Komanduri, R., Zhang, B. and Vissa, C. M. (1991). Machining of fiber reinforced composites. *Machining Science and Technology*, 1: 113-152.
Kouzeli, M. and Mortensen, A. (2002). Size dependent strengthening in particle reinforced aluminium. *Acta Materialia*, 50: 39-51.
Krautkramer, J. (1983). *Ultrasonic Testing of Materials*, (3th eds). Springer-Verlag, Berlin, Germany.
Krautkramer, J. and Krautkramer. H. (1990). *Ultrasonic Testing of Materials*. (4th ed). Springer-Verlag, Berlin. Germany.
Kruger, S. E., Rebello, J. M. A. and De Camargo, P. C. (1999). Hydrogen damage detection by ultrasonic spectral analysis, *NDT E. International*. 32: 275–281.
Kumar, A., Jaykumar, T. and Raj, B. (2006). Influence of precipitation of intermetallics on Young's modulus in nickel and zirconium base alloy. *Philosophical Magazine Letters*. 86:579-587.
Kumar, A., Jayakumar, T., Raj, B. and Ray, K. K. (2003). Correlation between ultrasonic shear wave velocity and poisson's ratio for isotropic solid materials. *Acta Materialia*, 51: 2417–2426.
Kumar, R. (2017). Liquid state fabrication of metal matrix composite using stir casting. International Journal of Advanced Research in Science and Engineering, 03: 214-219.
Kuttruff, H. (1991). *Ultrasonics Fundamentals and Applications*. Applied Science, Elsevier, New York.
Kwon, H., Cho, S., Leparoux, M. and Kawasaki, A. (2012). Dual-nanoparticulate-reinforced aluminum matrix composite materials. *Nanotechnology, 23:* 225704.
Kwon, H., Lee, G. G., Kim, S. G., Lee, B. W., Seo, W. C. and Leparoux, M. (2015). Mechanical properties of nanodiamond and multi-walled carbon nanotubes dual-reinforced aluminum matrix composite materials, *Materials Science and Engineering: A*, 632: 72–77.
Kwon, H., Saarna, M.,Yoon, S., Weidenkaff, A. and Leparoux, M. (2014). Effect of milling time on dual-nanoparticulate-reinforced aluminum alloy matrix composite materials, *Materials Science and Engineering: A*, 590:338–345.
Lau, K. T., Chipara, M., Ling, H. Y. and Hui, D. (2004). On the effective elastic moduli of carbon nanotubes for nanocomposite structures. *Composites Part B: Engineering*, 35: 95-101.
Lee, D. F. (1987). *Ultrasonic Nondestructive Characterization of SiC-Reinforced Aluminum Metal-Matrix Composites.* Masters Thesis, University of Houston, USA.
Liao, J. and Tan, M. J. (2011). Mixing of carbon nanotubes (CNTs) and aluminum powder for powder metallurgy use. *Powder technology*, 208: 42-48.
Liaw, P. K., Pitchumani, R., Hsu, D. K., Jeong, H. and Yao, S. C. (1994). Nondestructive eddy-current evaluation of anisotropic conductivities of silicon-

carbide reinforced aluminium metal-matrix composite extrusions, *Journal of Engineering for Gas Turbines and Power (Trans ASME)*, 116: 647- 656.

Liaw, P. K., Shannon, R. E., Clark, W. G., Harrigan, W. C., Jeong, H. and Hsu, D. K. (1992). Determining material properties of metal-matrix composites by NDE. JOM: *Journal of the Minerals, metals, and Materials Society*, 44: 36-40.

Li, Q, Zaiser, M. and Koutsos, V. (2004). Carbon nanotube/epoxy resin composites using a block copolymer as a dispersing agent. *physica status solidi (a)*, 201: 89-91.

Li, Y. B., Wei, B. Q., Liang, J., Yu, Q. and Wu, D. H. (1999). Transformation of carbon nanotubes to nanoparticles by ball milling process. *Carbon*, 37: 493-497.

Li. X. (2012). *Eddy current techniques for non-destructive testing of carbon fibre reinforced plastic* (CFRP). Phd Thesis, University of Manchester. UK.

Liu, F., Zhang, X., Cheng, J., Tu, J., Kong, F., Huang, W. and Chen, C. (2003). Preparation of short carbon nanotubes by mechanical ball milling and their hydrogen adsorption behavior. *Carbon*, 41: 2527-2532.

Lloyd, D. J. (1994). Particle reinforced aluminium and magnesium matrix composites. *International Materials Reviews*, 39: 1-23.

Lobkis, O. I., Yang, L., Li, J. and Rokhlin, S. I. (2012). Ultrasonic backscattering in polycrystals with elongated single phase and duplex microstructures. *Ultrasonics*, 52: 694–705.

Lü, L. and Lai, M. O. (1998). *Mechanical alloying*. Kluwer Academic Publishers, Boston, USA.

Lu, Y. and Liaw, P. K. (1995). Effects of particle orientation in SiC particulate reinforced aluminium matrix composite extrusions on ultrasonic velocity measurement. *Journal of Composite Materials*, 29: 1096-1115.

Maggi, L. E., Silva, C. E. R., Alvarenga, A. V. and Costa-Felix, R. P. B. (2011). Ultrasonic calibration and certification of V1 and V2 type reference standard blocks for use in Non-Destructive Testing, *Journal of Physics: Conference Series* 279: 012029.

Mahboob, H., Sajjadi, S. A. and Zebarjad, S. M. (2008). *Synthesis of Al-Al_2O_3 nanocomposite by mechanical alloying and evaluation of the effects of ball milling time on the microstructure and mechanical properties*. The International Conference on MEMS and Nanotechnology, ICMN'08, Kuala Lumpur Malaysia.

Mamalis, A. G., Vogtländer, L. O. G. and Markopoulos, A. (2004). Nanotechnology and nanostructured materials: trends in carbon nanotubes. *Precision Engineering*, 28: 16-30.

Manjula, K., Vijayarekha, B., Venkatraman, D. and Karthik, L. (2012). Ultrasonic time of flight diffraction technique for weld defects: A review, *Journal of Applied Science and Engineering Technology*. 4: 5525-5533.

Manocha, L. M., Valand, J., Patel, N., Warrier, A. and Manocha, S. (2006). Nanocomposites for structural applications. *Indian Journal of Pure and Applied Physics*, 44:135-142.

Mazaheri, Y., Karimzadeh, F. and Enayati, M. H. (2010). Nanoindentation study of Al356-Al_2O_3 nanocomposite prepared by ball milling, *Materials Sciences and Applications*, 1: 217-222.

Mazilkin, A. A. and Myshlyaev, M. M. (2006). Microstructure and thermal stabilityof superplastic aluminium—lithium alloy after severe plastic deformation. *Journal of materials science*, 41: 3767-3772.

Ma, Z. Y., Li, Y. L., Liang, Y., Zheng, F., Bi, J. and Tjong, S. C. (1996). Nanometric Si_3N_4 particulate-reinforced aluminum composite. *Materials Science and Engineering: A*, 219: 229-231.

McNaught, A. D. (1997). *Compendium of chemical terminology*. Oxford, Blackwell Science, UK.

McWilliams, B., Yu, J., Pankow, M. and Yen, C. F. (2015). Ballistic impact behavior of woven ceramic fabric reinforced metal matrix composites. *International Journal of Impact Engineering,* 86: 57-66.

Meher, A. (2015). *Synthesis and characterization of Cu-graphite-SiC hybrid metal matrix composite prepared by powder metallurgy route*. Master Thesis. National Institute of Technology Rourkela, Rourkela, India.

Meyendorf, G. H., Rösner, H., Kram, V. and Sathish, S. (2002). Thermo-acoustic fatigue characterization. *Ultrasonics.* 40:427-434.

Miller, W. S., Zhuang, L., Bottema, J., Wittebrood, A. J., De Smet, P., Haszler, A. and Vieregge, A. (2000). Recent developments in aluminium alloys for the automotive industry. *Materials Science and Engineering A.* 280: 37–49.

Miracle, D. B. (2005). Metal matrix composites–from science to technological significance, *Composites Science and Technology*, 65: 2526–2540.

Miracle, D. B. and Donaldson, S. L. (2001). *ASM handbook* (Vol. 21). Materials Park, ASM International, USA.

Mix, P. E. (1987). *Introduction to ondestructive Testing*. John Wiley & Sons. New York, USA.

Mobasherpour, I., Tofigh, A. A. and Ebrahimi, M. (2013). Effect of nano-size Al_2O_3 reinforcement on the mechanical behavior of synthesis 7075 aluminum alloy composites by mechanical alloying. *Materials Chemistry and Physics,* 138: 535-541.

Mohamed, F. A. and Xun, Y. (2003). On the minimum grain size produced by milling Zn–22% Al. *Materials Science and Engineering: A,* 358: 178-185.

Monthioux, M. and Vladimir, L. K. (2006). Who should be given the credit for the discovery of carbon nanotubes?, *Carbon,* 44: 1621-1623.

Mora, E. P., Normando, P. G., Goncalvs, L. L. and Kruger, S. E. (2012). Characterization of cast iron microstructure through fluctuation and fractal analyses of ultrasonic backscattered signals combined with classification, *Journal of Nondestructive Evaluation,* 31: 90–98.

Morsi, K. and Esawi, A. M. K. (2007). Effect of mechanical alloying time and carbon nanotube (CNT) content on the evolution of aluminum (Al)–CNT composite powders. *Journal of Materials Science,* 42:4954–4959.

Morsi, K., El-Desouky, A., Johnson, B., Mar, A. and Lanka, S. (2009). Spark plasma extrusion (SPE): prospects and potential. *Scripta Materialia,* 61: 395-398.

Morsi, K., Esawi, A. M. K., Borah, P., Lanka, S., Sayed, A. and Taher, M. (2010). Properties of single and dual matrix aluminum–carbon nanotube composites processed via spark plasma extrusion (SPE). *Materials Science and Engineering A.* 527: 5686–5690.

Morsi, K., Esawi, A. M. K., Lanka, S., Sayed, A. and Taher, M. (2010). Spark plasma extrusion (SPE) of ball-milled aluminum and carbon nanotube reinforced aluminum composite powders. *Composites Part A: Applied Science and Manufacturing,* 41: 322–326.

Mott, G. and Liaw, P. K. (1998). Correlation of mechanical and ultrasonic properties of Al–SiC metal matrix composite. Metallurgical and Materials Transactions A, 19: 2233–2246.

Mourik, M., Chen Y. C. and Salama. K. (1997). Ultrasonic characterization of elastic anisotropy in aluminum-SiC and Al_2O_3 metal-matrix composites. *Review of Progress in Quantitative Nondestructive Evaluation,* 16: 1143-1150.

MPIF standard 28. (2016). *Method for Determination of Apparent Density of Non-Free-Flowing Metal Powders Using the Carney Apparatus*, MPIF publishers, Princeton, USA.

Mukhopadhyay, A. K. and Phani, K. K. (2000). An analysis of microstructural parameters in the minimum contact area model for ultrasonic velocity- porosity relations. *Journal of the European Ceramic Society*, 20:29 – 38.

Mukhopadhyay, N. K., Yadav, T. P. and Srivastava, O. N. (2002). An investigation on the transformation of the icosahedral phase in the Al-Fe-Cu system during mechanical milling and subsequent annealing. *Philosophical Magazine A*, 82: 2979-2993.

Murty, B. S. and Ranganathan, S. (1998). Novel materials synthesis by mechanical alloying/milling. *International materials reviews*, 43: 101-141.

Muthmari, S. and Singh, A. (2011). Review of various ultrasonic techniques employed in modern industries, *International Journal of Engineering Science*. 3: 3078-3085.

Mutlu, I., Ekinci, S. and Oktay E. (2014). Characterization of heat treated titanium-based implants by nondestructive eddy current and ultrasonic tests. *Journal of Materials Engineering and Performance*, 23: 2083-2091.

Nakashima, N. (2005). Soluble carbon nanotubes: fundamentals and applications. *International Journal of Nanoscience*, 4: 119-137.

Normando, P. G., Moura, E. P., Souza, J. A., Tavares, S. M. and Padovese, L. R. (2010). Ultrasound, eddy current and magnetic Barkhausen noise as tools for sigma phase detection on a UNS S31803 duplex stainless, *Material Science and Engineering A*. 527: 2886–2891.

Nanekar, P. P. and Shah, B. K. (2003). Characterization of material properties by ultrasonic, *BARC Newsletter*. 249: 25-38.

O'Donnel, G. and Looney, L. (2001). Production of aluminium matrix composite component using conventional PM technology. *Materials Science and Engineering A*. 303: 292–301.

Oghbaei, M. and Mirzaee, O. (2010). Microwave versus conventional sintering: A review of fundamentals, advantages and applications. *Journal of Alloys and Compounds*, 494: 175–189.

Ohtani, T., Nishiyama, K., Yoshikawa, S., Ogi, H. and Hirao, M. (2006). Ultrasonic attenuation and microstructural evolution throughout tension–compression fatigue of a low-carbon steel. *Material Science and Engineering A*. 442:466-470.

Oliver, W. C. and Pharr, G. M. (1992). An improved technique for determining hardness and elastic modulus using load and displacement sensing indentation experiments. *Journal of materials research*, 7: 1564-1583.

Orrhede, M. (1993). *Elastic Constants and Thermal Expansion of Aluminum/Silicon Carbide Composites*. Masters Thesis, University of Houston, USA.

Ostovan, F (2015). *Reinforcing aluminum matrix by CNTs and nano Alumina using powder metallurgy method*. PhD Thesis, Universiti Putra Malaysia.

Ostovan, F., Matori, K. A., Toozandehjani, M., Oskoueian, A., Yusoff, H. M., Yunus, R. and Ariff, A. H. M. (2015). Microstructural evaluation of ball-milled nano Al_2O_3 particulate-reinforced aluminum matrix composite powders. *International Journal of Materials Research*, 106: 636-640.

Ostovan, F., Matori, K. A., Toozandehjani, M., Oskoueian, A., Yusoff, H. M., Yunus, R. and Ariff, A. H. M. (2016). Nanomechanical behavior of multi-walled carbon nanotubes particulate reinforced aluminum nanocomposites prepared by ball milling. *Materials*, 9: 140.

Ostovan, F., Matori, K. A., Toozandehjani, M., Oskoueian, A., Yusoff, H. M., Yunus, R., Ariff, A. H. M., Quah, H. J. and Lim, W. F. (2015). Effects of CNTs content and milling time on mechanical behavior of MWCNT-reinforced aluminum nanocomposites. *Materials Chemistry and Physics*, 166: 160-166.

Ostovan, F., Matori, K. A., Yusoff, H. M., Yunus, R.; Ariff, A. H. M., Toozandehjani, M., Fadaeifard, F. and Meschian, M. R. (2014). Occurrence of pattern formation of microstructural, physical and mechanical properties of sintered pm steels containing pre-alloyed Astaloy E powder. *Transactions of the Indian Institute of Metals*, 67: 881-888.

Ostovan, F., Matori, K. A., Yusoff, H. M., Yunus, R,. Ariff, A. H. M., Toozandehjani, M. and Meschian, M. R. (2016). Investigation of the structure and hardness of quenched sintered materials produced from iron-base alloyed powders (Astaloy E). *Metal Science and Heat Treatment*, 58: 431-434.

Ozmetin, A. E., Sahin, O., Ongun, E. and Kuru, M. (2015). Mechanical characterization of MgB_2 thin films using nanoindentation technique. *Journal of Alloys and Compounds*, 619: 262–266.

Pandey, D. K. and Pandey, S. (2010). Ultrasonics: A Technique of Material Characterization. In Dissanayake. *D, Acoustic Waves*, InTech Publishers, Croatia.

Papadakis, E. P. (1999). *Ultrasonic Instruments and Devices Reference for Modern Instrumentation, Techniques, and Technology*. Academic Press, USA.

Papadakis, E. P. (1967) Ultrasonic phase velocity by pulse-echo overlap method incorporating diffraction phase corrections. The Journal of the Acoustical Society of America, 42:1045–1051.

Perez-Bustamante, R., Estrada-Guel, I., Amezaga-Madrid, P., Miki-Yoshida, M., Herrera-Ramirez, J. M. and Martinez-Sanchez, R. (2010). Microstructural characterization of Al–MWCNT composites produced by mechanical milling and hot extrusion. *Journal of Alloys and Compounds*, 495: 399–402**.**

Perez-Bustamante, R., Estrada-Guel, I., Antunez-Flores, W., Miki-Yoshida, M., Ferreira, P. J. and Martinez-Sanchez, R. (2008). Novel Al-matrix nanocomposites reinforced with multi-walled carbon nanotubes. *Journal of Alloys and Compounds,* 450: 323–326.

Pierard, N., Fonseca, A., Colomer, J. F., Bossuot, C., Benoit, J. M., Van Tendeloo, G. and Nagy, J. B. (2004). Ball milling effect on the structure of single-wall carbon nanotubes. *Carbon*, 42: 1691-1697.

Poirier, D., Gauvin, R. and Drew, R. A. L. (2009). Structural characterization of a mechanically milled carbon nanotube/aluminum mixture. *Composites A*, 40: 1482–1489.

Polmear, I.J. (2000). *Light Alloys- Metallurgy of the Light Metals,* 3th ed. Butterworth–Heinemann, Oxford, UK.

Popov, V. N. (2004). Carbon nanotubes: properties and application. *Materials Science and Engineering: R*, 43: 61-102.

Prasad, T., Yadav, R. M. and Singh, D. P. (2012). Mechanical milling: a top down approach for the synthesis of nanomaterials and nanocomposites. *Nanoscience and Nanotechnology*, 2: 22-48.

Pugh, S. F. (1954). Relations between the elastic moduli and the plastic properties of polycrystalline pure metals. *Philosophical Magazine*, 45: 823–843.

Rahman, M. H., EI-Sayed, A. T., Chen, Y. C. and Salama, K. (1999). ULTRASONIC velocity measurements applied to process control of metal matrix composites densifica tion. *Review of Progress in Quantitative Nondestructive Evaluation*, 18: 1281-1288.

Raihanuzzaman, R. M., Han, S. T., Ghomashchi, R., Kim, H. S. and Hong, S. J. (2015). Conventional sintering of WC with nano-sized Co binder: Characterization and mechanical behaviour. *International Journal of Refractory Metals and Hard Materials*, 53: 2-6.

Rajan, T. P. D. Pillai, R. M. and Pai, B. C. (1998). Reinforcement coatings and interfaces in aluminium metal matrix composites. *Journal of Materials Science*, 33: 3491-3503.

Raj, B. (1996). A perspective on materials characterization for technology advancement and industrial growth: Emphasis on non-destructive evaluation. *Bulletin of Materials Science*. 19: 839-855.

Raj, B. and Jayakumar, T. (1997). NDE methodologies for characterization of defects, stresses and microstructures in pressure vessels and pipe, *International Journal of Pressure Vessels and Piping*, 73: 133–146.

Rao, B. P. C., Jaykumar, T., Raj, B. and Arnold, W. (2001). Nondestructive characterization of martensite in AISI type 304 stainless steel using Squid and MBN methods. *Journal of nondestructive Evaluations.* 2: 38-43.

Raviathul Basariya, M., Srivastava, V. C. and Mukhopadhyay, N. K. (2014). Microstructural characteristics and mechanical properties of carbon nanotube reinforced aluminum alloy composites produced by ball milling. *Materials Design*, 64: 542-549**.**

Razavi Hesabi, Z., Hafizpour, H. R. and Simchi, A. (2007). An investigation on the compressibility of aluminum/nano-alumina composite powder prepared by blending and mechanical milling. *Materials Science and Engineering A*, 454-455: 89–98.

Razavi Hesabi, Z., Simchi, A. and Reihani, S. S. (2006). Structural evolution during mechanical milling of nanometric and micrometric Al_2O_3 reinforced Al matrix composites. *Materials Science and Engineering: A*, 428: 159-168.

Razavi Tousi, S. S., Yazdani Rad, R., Salahi, E., Mobasherpour, I. and M. Razavi. (2009). Production of Al–20 wt.% Al_2O_3 composite powder using high energy milling. *Powder Technology*, 192: 346-351.

Rawal, S. (2001). Metal-matrix composites for space applications. *JOM*, 53: 14-17.

Roberge, P. R. (2006). *Corrosion Basics: An Introduction*. 2nd ed, NACE Press, Houston, USA.

Robertson, J. (2004). Realistic applications of CNT. *Materials Today*, 7: 46–52.

Rohatgi, P. and Schultz, B. (2007). Light weight metal matrix composites – stretching the boundaries of metals. *Materials Letters*, 2: 16-9.

Rohatgi, P. (1991). Cast aluminum-matrix composites for automotive applications. *JOM*, 43: 10–15.

Rosen, M., Horowitz E., Swartzendruber, L., Fick, S. and Mehrabian, R. (1982). The aging process in aluminum alloy 2024 studied by means of eddy currents, *Materials Science and Engineering.* 53: 191-198.

Rossing, T. (1990). *The Science of Sound*. Reading, MA: Addison-Wesley.

Roth, D. J., Stang, D. B., Swickard, S. M., DeGuire, M. R. and Dolhert, L.E. (1991). Review, modeling and statistical analysis of ultrasonic velocity-pore fraction relations in polycrystalline materials. *Materials Evaluation*, 49:883-888.

Ruiz-Navas, E. M., Fogagnolo, J. B., Velasco, F., Ruiz-Prieto, J. M. and Froyen, L. (2006). One step production of aluminium matrix composite powders by mechanical alloying. *Composites Part A: Applied Science and Manufacturing*, 37: 2114-2120.

Safari, J., Akbari, G. H., Shahbazkhan, A. and Delshad Chermahini, M. (2011). Microstructural and mechanical properties of Al–Mg/Al_2O_3 nanocomposite

prepared by mechanical alloying. *Journal of Alloys and Compounds*, 509: 9419-9424.
Saiz, E., Tomsia, A. P. and Suganuma, K. (2003). Wetting and strength at Al/α-alumina interface. *The Journal of the European Ceramic Society*, 23: 2787–2796.
Salih, O. S., Ou, H., Sun, W. and McCartney, D. G. (2015). A review of friction stir welding of aluminium matrix composites. *Materials Design*, 86: 61-71.
Salvetat, J. P., Bonard, J. M., Thomson, N. H., Kulik, A. J., Forro, L., Benoit, W. and Zuppiroli, L. (1999). Mechanical properties of carbon nanotubes, *Applied Physics A: Materials Science and Processing*, 69: 255-260.
Santhosh Kumar, S., Seshu Bai, V., Rajkumar, K. V., Sharma, G. K., Jayakumar, T. and Rajasekharan, T. (2009). Elastic modulus of Al–Si/SiC metal matrix composites as a function of volume fraction. *Journal of Physics D: Applied Physics*, 42: 175504.
Saravanan, C., Subramanian, K., Ananda Krishnan, V. and Sankara Narayanan, R. (2015). Effect of Particulate reinforced aluminium metal matrix composite–A review. *Mechanics and Mechanical Engineering*, 19:23–30.
Schatt, W. and Wieters, K. P. S. (1997). *Powder Metallurgy Processing and Materials.* EPMA, Shrewsbury, UK.
Schey, J. (2007). *Introduction to Manufacturing Processes*. McGraw Hill. New York, USA.
Schwartz, M. M. (1984). *Composite Materials Handbook*. McGraw-Hill, New York, USA.
Schwarz, R. B. (1996). Introduction to the Viewpoint set on: mechanical alloying. *Scripta Materialia*, 34: 1-4.
Schwarz, R. B. and Johnson, W. L. (1983). Formation of an amorphous alloy by solid-state reaction of the pure polycrystalline metals. *Physical Review Letters*, 51: 415-418.
Sears, F. M. and Bonner, B. P. (1981). Ultrasonic attenuation measurement by spectral ratios utilizing signal processing techniques. *IEEE Transactions on Geoscience and Remote Sensing*, GE-19: 95–99.
Shelly, J. S., LeClaire, R. and J. Nichols, J. (2001). Metal-matrix composites for liquid rocket engines. *JOM*, 53: 18–21.
Shingu, P. H. and Watanabe, R. (1995). Special issue on mechanical alloying. *Materials Transactions*, 36: 383-388.
Shyong, J. H., Gie, C. T. and Huang, C. H. (1998). *The Nondestructive Characterization of Metal-Matrix Composites.* Proceeding of The 5 Int'I Conference on Composites Engineering, Las Vegas, Nevada.
Sidek, H. A. A., Chow, S. P., Talib, Z. A. and Halim, S. A. (2003). Formation and elastic behavior of lead-magnesium chlorophosphate glasses, *Turkish Journal of Physics*, 28: 65-72.
Silvestre, N., Bruno, F. and José, N. C. L. (2014). Compressive behavior of CNT-reinforced aluminum composites using molecular dynamics. Composites Science and Technology, 90: 16-24.
Sinclair, I. and Gregson, P. J. (1997). Structural performance of discontinuous metal matrix composites. *Materials science and technology*, 13: 709-726**.**
Singer, R. F., Oliver, W. C. and Nix, W. D. (1980). Identification of dispersoid phases created in aluminum during mechanical alloying. *Metallurgical Transactions A*, 11: 1895-1901.
Singh, H., Sarabjit, Jit N. and Tyagi, A. K. (2011). An overview of metal matrix composite processing and SiC based mechanical properties, *Journal of Engineering Research and Studies*, 2: 72–78.

Smith, R. L. (1983). Ultrasonic attenuation, microstructure and ductile to brittle transition temperature in Fe–C alloys. *Journal of Nondestructive Evaluation*. 41:219-222.

Smith, W. F. (1990). *Principles of Material Science and Engineering*. 2nd ed, McGraw-Hill, New York, USA.

Soma Raju, K., Bhanu Prasad, V. V., Rudrakshi, G. B. and Ojha, S. N. (2003). PM processing of Al-Al_2O_3 composites and their characterisation. *Powder metallurgy*, 46: 219-223.

Srivatsan, T. S., Ibrahim, I. A., Mohamed, F. A. and Lavernia, E. J. (1991). Processing techniques for particulate-reinforced metal aluminium matrix composites. *Journal of Materials Science*, 26: 5965–5978.

Surappa, M. (2003). Aluminium matrix composites: Challenges and opportunities. *Sadhana*, 28: 319–334.

Suryanarayana, C. (2001). Mechanical alloying and milling. *Progress in materials science*, 46: 1-184.

Suryanarayana, C. and Al-Aqeeli, N. (2013). Mechanically alloyed nanocomposites. *Progress in Materials Science*, 58: 383-502.

Suryanarayana, C. (1995). *Mechanical Alloying and Milling: A Bibliography, 1970-1994*. Cambridge Intersicence Publishing, UK.

Suryanarayana, C. and Gerant Norton. M. (1998). *X-Ray Diffraction: A Practical Approach*. Plenum, New York, USA.

Tan, X., Wang, J., Xu, Y., Curran, R., Raghunathan, S., Gore, D. and Doherty, J. (2008). Cost-efficient materials in aerospace: composite vs aluminium. Proceedings of the 15th ISPE International Conference on Concurrent Engineering (CE2008), Belfast, UK.

Tang, F. Anderson, I. E. and Biner. S. B. (2002). Solid state sintering and consolidation of Al powders and Al matrix composites, *Journal of Light Metals*, 2: 201–214.

Tavoosi, M., Karimzadeh, E. and Enayati, M. H. (2008). Fabrication of Al–Zn/α-Al_2O_3 nanocomposite by mechanical alloying. *Material Letters*, 62: 282-285.

Taya, M. and Arsenault. R. J. (1989). *Metal Matrix Composites*, Elsevier Science Publishers Ltd. Netherland.

Thakur, S. K., Srivatsan, T. S. and Gupta, M. (2007). Synthesis and mechanical behavior of carbon nanotube–magnesium composites hybridized with nanoparticles of alumina. *Materials Science and Engineering: A*, 466: 32-37.

Tham, L. M., Gupta, M. and Cheng, L. (2001). Effect of limited matrix–reinforcement interfacial reaction on enhancing the mechanical properties of aluminium–silicon carbide composites. *Acta Materialia*, 49: 3243-3253.

Thomson, K. E., Jiang, D., Ritchie, R. O. and Mukherjee, A. K. (2007). A preservation study of carbon nanotubes in alumina-based nanocomposites via Raman spectroscopy and nuclear magnetic resonance. Applied Physics A, 89: 651-654.

Toozandehjani, M. (2014). Characterization of age hardening treatment of AA6061 aluminum alloy through destructive and non-destructive testing techniques. Master Thesis. Universiti Putra Malaysia, Malaysia.

Toozandehjani, M., Matori, K. A., Ostovan, F., Mustapha, F., Zahari, N. I. and Oskoueian, A. (2015). On the correlation between microstructural evolution and ultrasonic properties: a review. *Journal of materials science*, 50: 2643-2665.

Toozandehjani, M., Matori, K. A., Ostovan, F., Sidek, A. A. Shuhazlly M. M. (2017). Effect of milling time on the microstructure, physical and mechanical properties of Al-Al_2O_3 nanocomposite synthesized by ball milling and powder metallurgy. Materials, 10.

Toozandehjani, M., Mustapha, F., Ariffin, M. K. A., Zahari, N. I., Matori, K. A. and Ostovan, F (2016). Influence of artificial aging treatment on the microstructure and mechanical behavior of AA6061-T6 aluminum alloy. *Metal Science and Heat Treatment*, 58: 283-286.

Toozandehjani, M., Mustapha, F., Ariffin, M. K. A., Zahari, N. I., Matori, K. A. and Ostovan, F. (2015). Characterization of aging behavior of AA6061 aluminum alloy through destructive and ultrasonic non-destructive testing techniques. *Transactions of the Indian Institute of Metals*, 68: 561-569.

Toozandehjani, M., Mustapha, F., Ariffin, M. K. A., Zahari, N. I., Matori, K. A. and Ostovan, F (2014). *Qualification of precipitation hardening of aluminum alloys by using non-destructive ultrasonic techniques*, Proceedeing of Iran International Aluminum Conference (IIAC201), Tehran, Iran.

Torralba, J. M., Da Costa, C. E. and Velasco, F. J. (2003). P/M aluminum matrix composites: An overview. *Journal of Materials Processing Technology*, 133:203-206.

Treacy, M. M. J., Ebbesen T. W. and Gibson J. M. (1996). Exceptionally high Young's modulus observed for individual carbon nanotubes. *Nature*, 381: 678 - 680.

Uozumi, H., Kobayashi, K., Nakanishi, K., Matsunaga, T., Shinozaki, K., Sakamoto, H. and Yoshida, M. (2008). Fabrication process of carbon nanotube/light metal matrix composites by squeeze casting. *Materials Science and Engineering: A*, 495: 282-287.

Varol, T. and Canakci, A. (2013). Effect of particle size and ratio of B_4C reinforcement on properties and morphology of nanocrystalline Al2024-B_4C composite powders. *Powder Technology*, 246: 462-472.

Vary, A. (1998). Concepts for interrelating ultrasonic attenuation, microstructure and fracture toughness in polycrystalline solids. *Journal of Materials Evaluation*. 46: 642-649.

Vasudevan, M. and Palanichami, P. (2002). Characterization of microstructural changes during annealing of cold worked austenitic stainless steel using ultrasonic velocity measurements and correlation with mechanical Properties. *Journal of Material Engineering Performance*. 11:169-179.

Verma, J., Kumar, A., Chandrakar, R. and Kumar, R. (2012). Processing of 5083 aluminum alloy reinforced with alumina through microwave sintering. *Journal of Minerals and Materials Characterization and Engineering*, 11: 1126-1131.

Vogt, T. K. (2002). *Determination of material properties using guided waves*. Phd dissertation. Imperical college of science, technology and medicine, UK.

Wang, H. M., Li, G. Zhao, Y. and Chen, G. (2010). In situ fabrication and microstructure of Al_2O_3 particles reinforced aluminium matrix composites, *Materials Science and Engineering A*, 527: 2881-2885.

Wang, L., Choi, H., Myoung, J. M. and Lee, W. (2009). Mechanical alloying of multi-walled carbon nanotubes and aluminium powders for the preparation of carbon/metal composites. *Carbon*, 47: 3427-3433.

Wang, N., Zhou, Z. and Lu, G. (2011). Microstructural evolution of 6061 alloy during isothermal heat treatment. *Journal of Material Science and Technology*. 27: 8-14.

Wang, R. M., Zheng, S. R. and Zheng, Y. P. (2011). *Polymer Matrix Composites and Technology*. woodhead publishing, UK.

Weeber, A. W. and Bakker, H. (1988). Amorphization by ball milling. A review. *Physica B: Condensed Matter*, 153: 93-135.

Wessel, J. K. (2004). *The HandBook of Advanced Materials*. John Wiley & Sons, New York, USA.

Westbrook, J. H. and Fleischer, R. L. (1995). *Intermetallic compounds: principles and practice*. John Wiley & Sons, New York.
Williamson, G. K. and Hall, W. H. (1953). X-ray line broadening from filed aluminium and wolfram. *Acta metallurgica*, 1: 22-31.
Wong, E. W., Sheehan, P. E. and Lieber: C. M. (1997). Nanobeam mechanics: elasticity, strength, and toughness of nanorods and nanotubes. *Science*, 277: 1971-1974.
Wu, J. G., Zhou, S. Y and Li, X. C. (2015). Ultrasonic attenuation based inspection method for scale-up production of A206–Al_2O_3 metal matrix nanocomposites. *Journal of Manufacturing Science and Engineering*, 137: 011013.
Xu, W. and Kaufman, J. J. (1993). Diffraction correction methods for insertion ultrasound attenuation estimation. IEEE Transactions on Biomedical Engineering, 40: 563-570.
Yadav, V. (2011). *Spark plasma sintering of aluminum matrix composites*. Master Thesis. Oklahoma State University, USA.
Yang, M., Koutsos V. and Zaiser M. (2007). Size effect in the tensile fracture of single-walled carbon nanotubes with defects. *Nanotechnology,* 18: 155708.
Yassen, Y., Ismail, M.P., Jemain, A.A. and Daud, A.R. (2011). Reliability of ultrasonic measurement of thickness loss caused by corrosion. *Insight Nondestructive Testing and Condition Monitoring*. 53:658-663.
Yeh, X. L., Samwer, K. and Johnson, W. L. (1983). Formation of an amorphous metallic hydride by reaction of hydrogen with crystalline intermetallic compounds—A new method of synthesizing metallic glasses. *Applied Physics Letters*, 42: 242-243.
Yu, M. F., Files, B. S., Arepalli, S. and Ruoff, R. S. (2000). Tensile loading of ropes of single wall carbon nanotubes and their mechanical properties. *Physical review letters,* 84: 5552.
Yu, M. F., Lourie, O., Dyer, M. J., Moloni, K., Kelly, T. F. and Ruoff, R. S. (2000). Strength and breaking mechanism of multiwalled carbon nanotubes under tensile load. *Science,* 287: 637-640.
Zawrah, M. F., Zayed, H. A., Essawy, R. A., Nassar, A. H. and Taha, M. A. (2013). Preparation by mechanical alloying, characterization and sintering of Cu–20 wt.% Al_2O_3 nanocomposites, *Materials and Design,* 46: 485-490.
Zebarjad, S. M. and Sajjadi, S. A. (2007). Dependency of physical and mechanical properties of mechanical alloyed Al–Al_2O_3 composite on milling time. *Materials design,* 28: 2113-2120.
Zebarjad, S. M. and Sajjadi, S. A. (2006). Microstructure evaluation of Al–Al_2O_3 composite produced by mechanical alloying method. *Materials design,* 27: 684-688.
Zhan, G. D., Kuntz, J. D., Wan, J. and Mukherjee, A. K. (2003). Single-wall carbon nanotubes as attractive toughening agents in alumina-based nanocomposites. *Nature materials,* 2: 38-42.
Zhang, Z. and Chen, D. L. (2008). Contribution of Orowan strengthening effect in particulate reinforced metal matrix nanocomposites. *Materials Science and Engineering: A,* 483–484:148–152.
Zhang, X. C., Xu, B. S., Xuan, F. Z., Tu, S. T., Wang, H. D. and Wu, Y. X. (2009). Porosity and effective mechanical properties of plasma-sprayed Ni-based alloy coatings. *Applied Surface Science*, 255: 4362-4371.
Zhao, L., and Gao, L. (2003). Stability of multi-walled carbon nanotubes dispersion with copolymer in ethanol. *Colloids and Surfaces A: Physicochemical and Engineering Aspects,* 224: 127-134.

Zhou, F., Lee, J. and Lavernia, E. J. (2001). Grain growth kinetics of a mechanically milled nanocrystalline Al. *Scripta materialia*, 44: 2013-2017.

Zhu, Y., Tian, G.Y., Lu, R.S. and Zhang, H. (2011). A review of optical NDT technologies. *Sensors*. 11: 7773-7798.