



UNIVERSITI PUTRA MALAYSIA

***VIABILITY OF MICROWAVE HYBRID SINTERING PROCESS FOR
TUNGSTEN CARBIDE CERMETS***

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**VIABILITY OF MICROWAVE HYBRID SINTERING PROCESS FOR
TUNGSTEN CARBIDE CERMETS**

By

SHAHDURA BTE HAMMAD THAURI

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in
Fulfillment of the Requirements for the Degree of Master of Science**

September 2016

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Master of Science

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September 2016

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Microwaves processing ceramics is fast emerging as a new field of ceramic processing and material synthesis, the past year has witnessed significant progress in the aspects of commercialization and application of the technology to new areas. Due to that reason, several experiments have been conducted on microwaves heating of ceramics. The aim of the study is to investigate the influence of several binder such as Nickel, Ferum, Chromium and Cobalt to Tungsten Carbide. The study involved the density and hardness of the sintered samples. The samples were compacted using the instron machine and sintered in microwave hybrid sintering setup for two different of soaking time (10 minutes and 20 minutes). Samples were comparing in terms of the effect of the soaking time on the samples and different binder between Ni-Fe and Ni-Cr, Co-Cr and Co-NiFe that being mix with tungsten carbide. For soaking time of 10 minutes shows a better density and hardness result compared to 20 minutes. In comparison between binder of Nickel and Ferum (Ni-Fe) and Nickel and Chromium (Ni-Cr), binder of Ni and Fe shows a better result compare to Ni and Cr binder. For binder with Cobalt, Nickel and Ferum (Co-Ni-Fe) has an enhanced result compare to binder Co and Cr (Co-Cr). Thus this prove that, Tungsten Carbide (Wc) inserts with several binders can be made using microwave sintering. With the hardness result, insert can be used for machining process to produce tool insert. The composition of powder, density and hardness result may be used depending on specific application.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk Ijazah Master Sains.

**KEMAJUAN PROSES PENSINTERAN KETUHAR GELOMBANG MIKRO
BAGI MENGHASILKAN SERMET TUNGSTEN CARBIDE**

Oleh

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Ketuhar gelombang mikro pemrosesan seramik muncul dengan pantas sebagai satu bidang baru pemrosesan seramik dan sintesis bahan, tahun lepas telah menyaksikan kemajuan yang ketara dalam aspek pengkomersilan dan penggunaan teknologi untuk bidang-bidang baru. Oleh sebab itu, beberapa ujikaji telah dijalankan ke atas pemanasan ketuhar gelombang mikro seramik. Tujuan kajian ini adalah untuk menyiasat pengaruh beberapa pengikat seperti nikel, Ferum, Kromium dan Cobalt untuk digabungkan bersama Tungsten Carbide. Kajian ini turun membincangkan tentang kepadatan dan kekerasan sampel yang telah dibakar. Sampel yang telah dipadatkan menggunakan mesin instron dan di bakar di dalam ketuhar gelombang mikro hibrid dibezakan dengan masa pembakaran yang dikekalkan (10 minit dan 20 minit) pada suhu yang sama. Sampel telah dibandingkan dari segi kesan masa yang dikekalkan pada sampel dan pengikat yang berbeza antara Ni-Fe dan Ni-Cr, Co-Cr dan Co-NiFe yang telah dicampurkan bersama tungsten carbide. Untuk masa pembakaran 10 minit menunjukkan kepadatan dan kekerasan keputusan yang lebih baik berbanding dengan 20 minit. Dalam perbandingan antara pengikat daripada nikel dan Ferum (Ni- Fe) dan Nikel dan Kromium (Ni- Cr), pengikat Ni dan Fe menunjukkan keputusan yang lebih baik berbanding dengan Ni dan Cr. Untuk pengikat dengan Cobalt , Nikel dan Ferum (Co-Ni- Fe) mempunyai hasil yang lebih bagus berbanding dengan pengikat Co dan Cr (Co-Cr) . Oleh itu, ini membuktikan bahawa , Tungsten Carbide (Wc) boleh dibakar menggunakan ketuhar gelombang mikro bersama dengan pengikat yang dinyatakan. Dengan keputusan kekerasan , insert boleh digunakan untuk proses pemesinan untuk menghasilkan alat insert. Komposisi serbuk, ketumpatan dan hasil kekerasan boleh digunakan bergantung pada aplikasi tertentu yang diperlukan.

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I certify that a Thesis Examination Committee has met on 10 September 2016 to conduct the final examination of Shahdura bte Hammad Thauri on her thesis entitled "Viability of Microwave Hybrid Sintering Process for Tungsten Carbide Cermets" in accordance with the Universities and University Colleges 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 Master of Science.

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CHAPTER 1

INTRODUCTION

1.1 Background

Powder metallurgy (PM) is a process whereby a material powder is compacted as a green body and sintered to a net shape at elevated temperatures. There are challenging demands from the PM industry for new and improved sintering process with finer microstructures and enhanced physical and mechanical properties.

PM components can be made by pressing and sintering of powders. The major processing steps are compaction and sintering. PM have been involved in a lot of process such as studies of properties and microstructure of a samples, studies on grain growth control in sintering process (Agrawal *et al.* 2000, and Wensheng *et al.* 2012). There have been a lot of researchers that used conventional sintering. A newer process exist such as plastic sintering, liquid phase sintering, spark plasma sintering and pressureless sintering. However, microwave heating is different from all of the conventional one which the way the heat transfer by radiant and convection heating. In contrast, microwave energy is delivered directly to the material through molecular interaction with the electromagnetic field. Microwave heating is the transfer of electromagnetic energy to thermal energy and is energy conversion rather than heat transfer (Kitawan and Atong, 2004).

Traditional process of sintering involved heating in slower rate less than 10°C per minute (Zhou *et al.*, 2009) It is not only increase the process time, but also results in significant microstructure coarsening (grain growth) during sintering, leading to the degradation of mechanical properties (Avikit *et al.*,2009). Hence it is envisaged that a fast heating rate would mitigate this problem. (Upadhayaya *et al.*, 2007). Conventional sintering heating occurs due to surface heating, which it is a conduction from the heating elements through the oven wall and holding vessel, and from outside to the inside of the sample (Breval *et al.*, 2005). Therefore all the heat energy, required for the sintering body must pass through its surface (Meredith *et al.* 2002).

New development and innovative ideas in the area of materials processing have often led to the discovery of new materials processing, with interesting and useful properties and new technologies which are faster, better, cheaper and greener. Striking examples of such innovations are recent developments in the area of microwave processing of ceramics. Although many potential advantages of utilizing microwaves to process ceramics have long been recognized, it is only now that this field has finally been shown to be take-off stage (Agrawal, 1998). Microwave heating was conceived over 50 years ago, its use in ceramic processing is relatively new. The starting material for most ceramics and similar materials is some type of powder that must somehow be glued together to make a solid. Some powders can be joined into a useful solid by simply

blending powder particles together by high temperature self-diffusions which this called sintering. This operation removes spaces between powder particles.

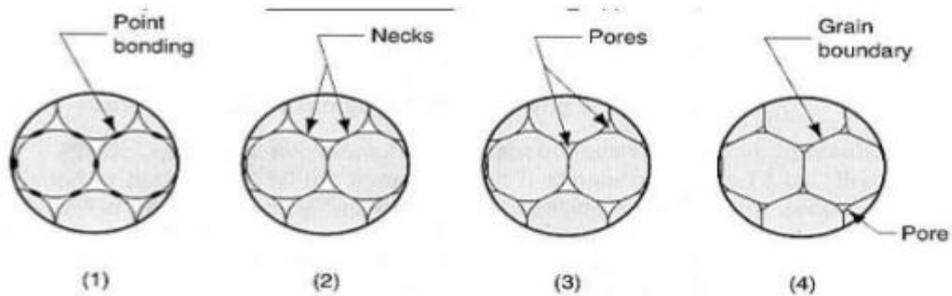


Figure 1.1 : Sintering on microscopic scale. The illustration shows different stages in development of grain boundaries between particles. (Agrawal, *et al.*, 2001)

The most popular sintering method to sinter tungsten carbide is vacuum sintering, which the result will lead to abnormal grain growth and widen the grain distribution (Rui *et al.*, 2012). This is not good to improve the performance. Therefore some researchers have try a few processes such as microwave sintering (Breval *et al.*, 2005, Agrawal *et al.*, 2002), spark plasma sintering (Sivaprahasam *et al.* 2007), high frequency induction-heated sintering (Kim and Shon, 2005, Kim and Guoj, 2005). Microwave sintering has been used in powder metallurgy due to the unparalleled characteristics such as accelerated heating rate, shortened processing cycle, high energy efficiency, fine and homogeneous microstructure, and enhanced mechanical performance (Ghuo *et al.*, 2010)

In order to meet the requirements of specific applications, WC hardmetals may contain small amounts of binding elements such as cobalt, nickel or iron. The use of Ni instead of Co as binder material could lead to a higher corrosion resistance (Hochstrasser-Kurz *et al.*, 2007). However, the mechanical properties of the WC composite containing nickel could be deteriorated since the hardmetals based on WC-Co usually have a better combination of mechanical properties compared to WC-Ni grades (Kny *et al.*, 1986). According to Almond and Roebuck (1988), the compressive properties of the WC-Co hardmetals are usually superior to those of WC-(Co-Ni) hardmetals. In most cases cobalt has been used as the tough metal binder phase, due to its excellent wetting, adhesion and adequate mechanical properties (Wentzel and Allen, 1997).

The exceptional wear resistance of cemented carbides, owing to the combination of a tough metal binder with hard carbide, has resulted in their applications in many engineering fields. In addition to their good performance in mining and cutting tool applications, cemented carbides are increasingly used in a variety of other industrial applications, such as seal rings, linings, valves, jet nozzles, saw blades, fluid mixers and conveyor belt scrapers. These applications differ from the traditional uses in that significantly longer lifetimes are demanded and components may be expected to remain

in service for several years. If components are not only subjected to wear processes but are also in contact with chemically aggressive environments, corrosion can play a major role in the degradation of the surface and can significantly accelerate wear (Human and Exner, 1996; Wentzel and Allen, 1997; Hochstrasser -Kurz *et al.*, 2007).

Interest and research activity in microwave processing has been continuously increasing, and the use of the microwave technology in industrial application is also growing with new developments in both engineering and design of microwave systems. This project is undertaken with the aim in understanding that microwave hybrid sintering is viable to produce sintered parts, the effect of hybrid microwave synthesis, sintering process and the effect of different binder mixing on the physical behavior of powder ceramic part with respect to hardness, density and microstructure of each sample.

1.2 Problem Statement

Common cutting tool inserts manufacturing involved powdered cutting materials being compacted into a final shape and then sintered under high temperature and pressure to produce a solid finished object. These finished components are then ready to be used as a cutting tool. Unfortunately, most of the results using conventional heating techniques do not often obtain finer microstructures. It involved slower heating rates which less than 10°C per minute (Zhou *et al.*, 2009). Moreover the microstructure coarsening during sintering which lead to degradation of mechanical properties (Avikit *et al.*, 2009). Furthermore, it requires higher usage of energy for the heating purposes. Besides, the heating occurs on surface which the sample heat by conduction heating from outside to inside of sample (Bredt *et al.*, 2005). Due to this, the surface temperature is much higher than the inside of the sample. That is why sample that heated using conventional heating always had these drawbacks which are surface cracking and swelling. This has led to microwave application in the development of ceramic material processing (Gupta and Wong, 2004; Kitiwan and Atong, 2004; Zhou *et al.* 2000). Microwave heating is believed can overcome these drawbacks due to way microwave heat it sample which it is by radiant and conduction heating. Sample where heated outside to inside and inside to outside by using the susceptor. Microwave heating is the transfer of the electromagnetic energy to thermal energy and it is energy conversion and not heat transfer as the conventional heating (Kitawan and Atong, 2004). Although microwave it has been stated before that measuring the temperature is not accurate due to the sample has to be taken out and the temperature is measured (Agrawal, 1998). However this problem has been overcome by installing the thermocouple inside the microwave.

Moreover it is believes that by mixing the WC with alternative binders will improve the hardness and microstructures of the sample (Schneider and George, 2001, Hanyaloglu and *et al.*, 2001). It also stated that the measurement of the hardness also depends on the composition of the powders and the binder powder that is used (Gupta *et al.*, 2011). Based on this idea of mixing with alternative binders with WC, this technique is believed to be applicable in producing cutting tool insert that can be use for industry that has high hardness and improve microstructure result. This will reduce the cost of replacing the tool thus lead to produce a better product. Strong sintering mechanism will produce strong bonding, reduce the wear rate, hence reducing the need for it to be

frequently replaced or resharpened (Stroud and Housten, 2000). Although there have been a lot of research study on several other binders, there is still no founding on using microwave hybrid sintering to sinter different mixing binder of tungsten carbide cermets. Therefore in this research it is believed that the use of microwave hybrid sintering is viable to sinter tungsten carbide cermets with different binders.

1.3 Objectives

- 1) To investigate the viability of microwave sintering to produce sintering parts.
- 2) Effect on sintering soaking time on the properties of sintered parts.
- 3) Effect of binders on the sintered components.

1.4 Research Scope

In this study, scopes of work are defined as follows:

- I. The matrix powder for this research is tungsten carbide, WC.
- II. The binders are Nickel, Chromium, Ferum and Cobalt.
- III. Microwave sintering is done in inert environment.

1.5 Thesis Organization

The first chapter of this thesis will introduce the general information on the powder metallurgy and microwave heating. It presents the problem statement and its significance, research objectives, research methodology and research scope.

Chapter Two explains more details on the literature review of the microwave hybrid sintering that been used in this research. The microwave heating mechanism of the microwave are such as penetrating radiations, rapid heating, controllable field distributions, selective heating of materials, and it is self limiting. Various microwave material interactions, where there are materials that does not absorb electromagnetic wave and materials that can interact with microwave.

Chapter Three highlights on the methodology applied in conducting this research starting from the literature review until the second phase of experimentation.

Chapter Four clarifies on the result and discussion obtained before the sintering and after the sintering. The density of the sample before and after the sintering will be compare. The hardness of each sample and the microstructure of the sample will be analyzed. It also includes the discussion of each result obtained.

Chapter Five concludes the overall results and recommends the optimum parameter for the machining operation.

REFERENCES

- Agrawal (1998), *Microwave processing of Ceramics*, Current opinion in Solid State & Materials Science, 3:480-485.
- Agrawal (2000), *Microwave sintering of ceramics, composites, metals and transparent materials*, Journal of Materials Education, 19: 49-58.
- Anklekar, M, Agrawal, Roy, (2013), *Improves mechanical properties and microstructural development of microwave sintered copper and nickel steel PM parts*, Powder Metallurgy, 44: 39-46.
- Bhaumik, S.K., Upadhaya, G.S., and M.L. Vaidya (1994), *Effect of Ti(C,N) Addition on Sintering Behaviour and Properties of Binder-Modified WC-10Co Cemented Carbide*, Journal of Material Science, 29(1):54-60.
- Bao, Jianhong Yi, Haoze Zhang, Y.Peng (2012), *Research on WC-8Co preparation by microwave sintering*, International Journal of Refractory Metals and Hard Materials, 32:16-20.
- Braginsky, Veena, Eugene, (2004), *Numerical simulation of solid state sintering*, International Journal of Solids and Structures, 42(2): 621-636.
- Bosser J, Ludwig C (1997), *Microwave sintering of titania* , Key Engineering Material 132-136 : 1022-1026.
- Breval, J.P Cheng, D.K Agrawal, P.Gigl, M.Denni, Roy, A.J Papworth (2004), *Comparison between microwave and conventional sintering of WC/Co composites*, Materials Science and Engineering ,A 391(1):285-295.
- Cheng, Agrawal, Komarneni, Manthis, Roy (1997), *Microwave processing of WC-Co composites and ferroic titanates*, Material Research Innovations, 1(1):44-52.
- Demirskyi , Ragulya , Agrawal (2011) , *Initial stage sintering of binderless tungsten Carbide powder under microwave radiation*, Ceramics International, 37(2):505-512.
- Daniel, Liu, Stander and Norgan (2008), *Alternative binder carbide tools for machining superalloys* , International Manufacturing Science and Engineering Conference, 417-425.
- Daniels, A. (1973), *Titanium carbide nickel composition process*, U.S. Patent No. 3,762,919.
- Durlu, N. (1999), *Titanium carbide based composites for high temperature applications*. Journal of the European Ceramic Society, 19(13), 2415-2419.
- Davis, J.R., Ed., (2005), *Alloying: Understanding the Basics*, ASM International.

- Davis, Robert F., H. Palmour, R. L. Porte (1982), *Emergent Process Methods for High-Technology Ceramics* (pp. 243-259). North Carolina: Springer Science & Business Media.
- Ettmayer, Kolaska, Lengauer, W. and Dreyer, K. (1995), *Ti(C,N) Cermets - Metallurgy and Properties*, International Journal of Refractory Metals and Hard Materials, 13(6), 343-351.
- Grellinger, Janney (1996), *Temperature measurement in a 2.45 GHz microwave furnace*, in: D.E. Clark, W.R. Tinga, J.R. Laia (Eds.), *Microwaves: Theory and Applications in Materials Processing II*, America Ceramic Society, Westerville, 529-538.
- Groover, M. P. (2007). *Fundamentals of modern manufacturing: materials processes, and systems*. United States of America: John Wiley & Sons.
- German, Randall M (1985), *Introduction to Liquid Phase Sintering*, Liquid Phase Sintering (pp. 1-11). United States of America: Springer Science Media.
- Gerdes, Porada (1994), *Microwave sintering of metal-ceramic and ceramic-ceramic composites*, Materials Research Society Symposium Proceedings, 347:531-537.
- Grab, Greenfield, and Santhanam (2005), *Chromium-containing cemented carbide body having a surface zone of binder enrichment*,” US Patent No. 6,866,921.
- General Carbide (2008), from: <http://www.generalcarbide.com/assets/pdf/GCDesignerGuide.pdf>
- Glas-Col Operating (2012), from: <https://www.glascol.com/>.
- Gupta, M., & Leong, E. W. W. (2008). *Microwaves and metals*. Singapore: John Wiley & Sons.
- Heinrich, H., Wolf, M., Schmidt, D., and Schleinkofer (2000), *Cermet having a binder with improved plasticity*, US Patent No. 6,024,776.
- Hanyaloglu, C., Aksakal, B., & Bolton, J. D. (2001). *Production and indentation analysis of WC/Fe-Mn as an alternative to cobalt-bonded hardmetals*. Materials Characterization, 47(3):315-322.
- Holleck, H., (1984), *Hard Alloy Comprising One or More Hard Phases and a Binary or Multicomponent Binder Metal Alloy*, US Patent #4,432,794.
- Huang, J. H., Zhou, G. A., Zhu, C. Q., Zhang, S. Q., & Lai, H. Y. (1995). *Influence of pre-alloyed Ni-Fe-Mo binder metal on properties and microstructure of tungsten heavy alloys*. Materials Letters, 23(1): 47-53.

- Kimrey, H. D., Kiggans, J. O., Janney, M. A. & Beaty, R. L. (1991). *Microwave sintering of zirconia-toughened alumina composites*. In: *Microwave Processing of Materials II*, Materials Research Society Symposium Proceedings, 189(243).
- Krage, M. K. (1981), *Microwave Sintering of Ferrites*. American Ceramic Society Bulletin. 60(11):1232-1234.
- Kitiwan and D. Atong (2006) *Synthesis and Characterization of Microwave and Conventional Combustion Synthesized Alumina-Titanium Carbide Powders*, Special Issue on Recent Advances in Materials and Processing [II] 49(1):85-90.
- Kitiwan, M., & Atong, D. (2004). Application of Microwave Energy for Synthesis and Sintering of Al₂O₃-TiC Ceramics. *Sigma*, 99, 0-1µm.
- Kennametal Turning Tool Catalog (2007), from : http://www.kennametal.com/en/products/mssg_products.jh.tml.
- Liu, Ma and Zhang (2012), *Properties and micro structural evolution of W-Ni-Fe*, International Journal of Refractory Metals and Hard Materials 35:138-142.
- Mukhopadhyay, Datta and Bassu (2008), *Prospects of Microwaves Processing: An Overview*, Central Glass and Ceramic Research Institute, Kolkata India.
- Mason, Wayne, (2002), *Inserts For Difficult Materials*, *Modern Machine Shop*, 74(8):82-86.
- Mondal, Upadhyaya and Agrawal (2010), *Microwave and conventional sintering of 90W-7Ni-3Cu alloys with premixed and prealloyed binder phase*, Materials Science and Engineering, A 527(26):6870-6878.
- Mondal, Upadhyaya and Agrawal (2010), *Microwave sintering of refractory metals/alloys: W, Mo, Re, W-Cu, W-Ni-Cu and W-Ni-Fe alloys*, Journal of Microwave power and Electromagnetic Energy, 44(1):28-44.
- Mondal, Upadhyaya, Agrawal (2010), *Effect of heating mode on sintering of tungsten*, International Journal of Refractory Metals and Hard Materials, 28(5):597-600.
- Mondal, Klein, Jaegermann, hahn, (1999), *Enhanced specific grain boundary conductivity in nanocrystalline Y₂O₃-stabilized zirconia*, Solid State Ionics, 118(3):331-339.
- Moskowitz, D., & Humenik Jr, M. (1966). *Cemented titanium carbide cutting tools*. In *Modern Developments in Powder Metallurgy* (pp. 83-94). US: Springer.
- Mondal, Agrawal, Upadhyaya (2008), *Microwave Sintering of Refractory Metals/alloys: W, Mo, Re, W-Cu, W-Ni-Cu and W-Ni-Fe Alloys*, Journal of Microwave Power and Electromagnetic Energy, 44(1):28-44.
- Menezes, Souto, Kiminami, (2007), *Microwave hybrid fast sintering of porcelain bodies*, Journal of materials processing technology, 190(1-3): 223-229.

- Mishra, P., Upadhyaya, A., & Sethi, G. (2006). *Modeling of microwave heating of particulate metals*. Metallurgical and Materials Transactions B, 37(5), 839-845.
- Menezes, R. R., Souto, P. M., & Kiminami, R. H. G. A. (2012). *Microwave Fast Sintering of Ceramic Materials in Sintering of Ceramics-New Emerging Techniques*.
- Prabhu, Chakraborty, Sarma (2008), *Microwave sintering of tungsten*, International Journal of Refractory Metals and Hard Materials 27(3):545-548.
- Pert, E., Carmel, Y., Birnboim, A., Olorunyolemi, T., Gershon, D., Calame, J., & Wilson, O. C. (2005). *Temperature measurements during microwave processing: the significance of thermocouple effects*. Journal of the American Ceramic Society, 84(9).
- Ramesh, P. D., Brandon, D., & Schächter, L. (1999). *Use of partially oxidized SiC particle bed for microwave sintering of low loss ceramics*. Materials Science and Engineering: A, 266(1): 211-220.
- Radu (2015), *Study on the chrome influence on the mechanical properties and microstructure of the tungsten based alloys*, Applied Mathematics, Mechanics, and Engineering, 59(1).
- Rahaman, M. N. (1995). *Ceramic Processing and Sintering*. New York Marcel: Dekker. Incorporated.
- Roy et al 200, Agrawal, Cheng (2001), *An improved process and apparatus for the preparation of particulate or solid parts*, US Patents # 6,004,5005.
- Rui BAO, Jian-hong YI1, Yuan-dong PENG, Hao-ze Zhang (2013), *Effects of microwave sintering temperature and soaking time on microstructure of WC-8Co*, Transaction Nonferrous Metal. Society China 23:372-376.
- Rybakov, K. I., Olevsky, E. A., & Krikun, E. V. (2013). *Microwave sintering: fundamentals and modeling*. Journal of the American Ceramic Society, 96(4):1003-1020.
- Schneider and George, Tooling and Prouction,(2001), *Applied Manufacturing Process Planning*. Cleveland: Huebner Publications.
- Saitou (2006), *Microwave sintering of iron, cobalt, nickel, copper and stainless steel powders*
- Scripta Materialia, 54:875-879.
- Sutton, W. H. (1992) *Microwave Processing of Ceramics*, American Ceramic Society Bulletin. 68(2):376-386.

- Shu-dong, L., Jian-hong, Y., Ying-Li, G., Yuan-dong, P., Li-ya, L., & Jun-ming, R. (2009). *Microwave sintering W–Cu composites: analyses of densification and microstructural homogenization*. *Journal of Alloys and Compounds*, 473(1):L5-L9.
- Thanjekwayo, N. P. (2010). *The influence of Ru additions on the corrosion behaviour of WC-Co cemented carbide in corrosive media* (Doctoral dissertation). University of the Witwatersrand.
- Tinga, W. R. & Voss, A. G. (1968). *Microwave Power Engineering*, New York: Academic Pressed.
- Trent, E.M., and Wright, P. K., (2001), *Metal Cutting* (4th Edition) (pp. 58-74). USA: Butterworth, Heinemann Publisher.
- Thostenson, E. T., & Chou, T. W. (1999). *Microwave processing: fundamentals and applications. Composites Part A*, *Applied Science and Manufacturing*, 30(9):1055-1071.
- Upadhyaya and G. Swaminathan (2006), *Tubular Microwave Sintering Furnace with Inert and Reducing Gas Flushing for Sintering Metallic Samples*, Patent No. 1147/DEL/2006.
- Upadhyaya, A. (2000), *Processing Strategy for Consolidating Tungsten Heavy Alloys for Ordnance Applications*, *Materials Chemistry and Physics*, 67(1):101-110.
- Upadhyaya, S.K, Tiwari and P. Mishra (2006), *Microwave sintering of W-Ni-Fe alloy*, *Scripta Materialia*, 56(1):5-8.
- Wentzel, Allen (1995), *Erosion-corrosion resistance of tungsten carbide hard metals with different binder compositions*, *International Journal of Refractory Metals and Hard Metals* 15:63-69.
- Willer-Porada M (1997), *A microstructural approach to the origin of “microwave effects” in sintering ceramics and composites*, *Microwaves: Theory and Application in Materials Processing IV*, 153-163.
- Wroe R and Rowley A T (1999), *Microwave Assisted oxygenation of melt-processed bulk YBa₂Cu₃O₇₋₈ Ceramics*, *Journal Material Science*, 32(17):4541-4547.
- Wang, Binner and Vaidhayanathan (2006), *Evidence for the Microwave Effect During Hybrid Sintering*, *Journal of the American Society*, 89(6):1977–1984.
- Zhou, Wang, Liu, X.PWang, C.S liu, Q.F Fang (2012), *High performance tungsten synthesized by microwave sintering method*, *Journal of Refractory Metals and Hard Materials* 34:13-17.