# The Study of the Mechanical Properties of Aluminum-Silica Composite Using Powder Metallurgy.

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**Abstract**

In this work, a metal matrix composite (Al–Si) was produced using fossil silica sand as reinforcement. Powder Metallurgy method was employed to produce the composite to ensure adequate distribution of the $SiO_2$ particles in the aluminum matrix,. The composition of the aluminum and silica sand used in the composite production was in the ratio of 100%:0%, 97.5%:2.5%, 95.0%:5.0%, 92.5%:7.5%, 90.0%:10% and 87.5%:12.5%. The powdered aluminum used for the work was produced by the milling of aluminum foil to a particle size of 300µm. The blended powder was compacted at a pressure of 41.37MPa and sintered for one hour at a temperature of 450$^{o}$C. The sintered samples were subjected to compressive and hardness tests and the analyzed results showed a strong interfacial bonding between the silica sand and the aluminum matrix which also justified the high compressive strength obtained at 2.5% $SiO_2$ reinforcement. Physical properties such as density and water absorption rate were also determined. The compact with 7.5% $SiO_2$ gave the least water absorption rate and there was an increase in hardness of the composites up to 7.5% $SiO_2$ content, after which a sharp decrease was obtained. The silica reinforcement did not only improve the mechanical properties but also ensured a reduced mass per weight ratio by maintaining the low density of aluminum.

**Keywords:** Aluminum Powder, Silica sand, composite, Reinforcement, Matrix, Powder metallurgy, Sintering.

## 1. INTRODUCTION

Many of our modern technologies require materials with unusual combinations of properties that cannot be met by the conventional metal alloys, ceramics, and polymeric materials. This is especially true for materials that are needed for aerospace, underwater, and transportation applications. Aircraft engineers are increasingly searching for structural materials that have low densities, strong, stiff, and abrasion and impact resistant, and are not easily corroded. Frequently, strong materials are relatively dense; also, increasing the strength or stiffness generally results in a decrease in impact strength. Generally speaking, a composite is considered to be any multi-phase material that exhibits a significant proportion of the properties of both constituent phases such that a better combination of properties is realized [1]. According to this principle of combined action, better property combinations are fashioned by the judicious combination of two or more distinct materials [2]. The increase in demand for light weight components, therefore, primarily driven by the need to reduce energy consumption for variety of societal and structural components, has lead to increase in the use of aluminum [3]. Aluminum is a very light metal with good technological properties.

However, the low strength and low melting point of aluminum were always a great problem. A cheap and better method of solving these problems is the use of reinforced materials [4]. In this work, therefore, fossil silica sand was used in reinforcing aluminum. To ensure adequate distribution of the $SiO_2$ particles in the aluminum matrix, Powder Metallurgy method was employed in producing the specimens. While the other methods of production such as the liquid metallurgy have the problem of reinforcement segregation and clustering, inter-facial chemical reactions, highly localized porosity and poor inter-facial bonding, powder metallurgy products are almost free from such defects [5]. A very important advantage of powder metallurgy process also is the ability to produce net-shaped components, thereby minimizing machining operations.

Materials available for use in most structural applications such as the automobile and aerospace industries are yet to satisfy the design requirement in terms of reduced mass per weight ratio. Considering the recommendation of some metals like aluminum due to its light weight, much restriction still abound due to its low strength and low melting temperature. To raise the strength of aluminum, a reliable option has been by composite formation. E.N Gregolin, e-tal of the Department of Metallurgical and Materials Engineering, University of Campinas, Brazil, have studied the hot work-ability and mechanical properties of aluminum-silica composite [6]. However they only made use of 5% silica content. This composition was arbitrarily chosen, although they observed a significant increase in the ultimate tensile strength of the composite.

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## 2. MATERIALS AND METHODOLOGY

### 2.1 Aluminium Powder Production.

The powdered aluminum used for the work was produced by the milling of aluminum foil. The aluminum foil were cut into pieces, milled and reduced to powder having a particle size of 300μm using an electric blender.

**Figure 1. The picture of the Aluminum foil, before and after cutting.**

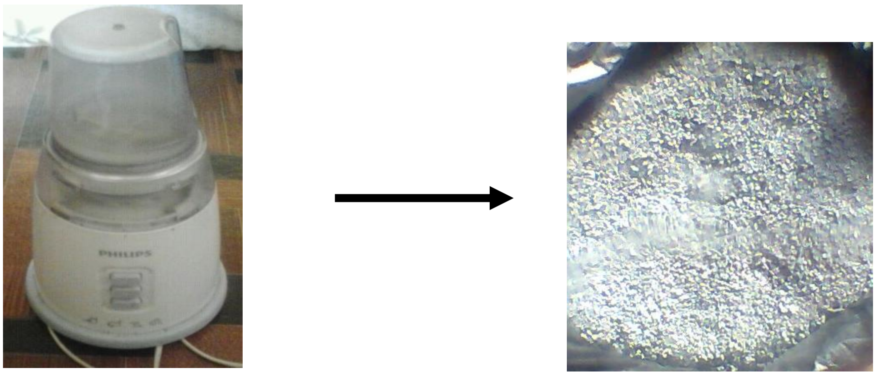

**Figure 2. The milling process with electric Blender blender.**

## 2.2 Volume Fraction Calculation.

This research was limited to six different compositions of aluminum-silica as follows:

**Table 1. The composition of Al and $SiO_2$ in each compact**

| Compact | %Al | % $SiO_2$ |
|---|---|---|
| 1 | 100 | 0 |
| 2 | 97.5 | 2.5 |
| 3 | 95 | 5 |
| 4 | 92.5 | 7.5 |
| 5 | 90 | 10 |
| 6 | 87.5 | 12.5 |

## 2.3 The Sintering Operation.

The compaction was done with a mounting press. The blended powder was put into the mould and a reasonable pressure of 41.37MPa was applied.

**Figure 3. The electric furnace.**


**Figure 4.The mounting press.**

The compacted samples were put into an electric furnace and allowed to stay for one hour at a temperature of 450$^{o}$C, so as to ensure the fusing together of the aluminum powder and the silica sand.

### 2.4 Water Absorption Test..

The water absorbed was calculated as percentage weight gain by the sample after it was immersed in water for a period of 24 hours and allowed to drain by gravity [8]

## 2.5 Density Test.

The mass of the specimen was determined by measurement while the volume of the samples were from determined from their dimensions. The density of the sample was then estimated from the equation below:

Density = $\frac{mass}{volume}$

## 2.6 Hardness Test.

The hardness of the sample was studied using a Vickers hardness testing machine. Based on ASTM specifications, the load applied was kept stable at 10kilos. The surfaces of the materials were well ground and polished and then indented with the diamond indenter. The indentation was viewed using the microscope and the variable slits were adjusted to be at the edges of the pyramid–shaped impression. The ocular reading is then noted and converted to the hardness number using the Vicker's Chart. [7]

## 2.7 Compression Test.

The compressive strength of the composites was determined using the Monsanto Tensometer.

**Figure 5. The Monsanto tensometer.**

## 3.0 RESULTS AND ANALYSIS

**Table 2. Comprehensive Stress-Strain Table for each of the Specimen.**

| %$SiO_2$ | | 2.5%$SiO_2$ | | 5%$SiO_2$ | | 7.5%$SiO_2$ | | 10%$SiO_2$ | | 12.5%$SiO_2$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Strain | Stress | Strain | Stress | Strain | Stress | Strain | Stress | Strain | Stress | Strain |
| .00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| .04 | 0.04 | 2.24 | 0.04 | 2.44 | 0.03 | 2.04 | 0.03 | 2.04 | 0.03 | 2.04 | 0.009 |
| .46 | 0.07 | 4.21 | 0.12 | 4.07 | 0.11 | 3.06 | 0.07 | 3.26 | 0.10 | 4.07 | 0.10 |
| .70 | 0.12 | 5.70 | 0.15 | 5.30 | 0.14 | 5.09 | 0.12 | 5.09 | 0.17 | 6.11 | 0.16 |
| .33 | 0.17 | 7.54 | 0.18 | 7.13 | 0.18 | 7.13 | 0.17 | 7.33 | 0.22 | 8.15 | 0.20 |
| .37 | 0.20 | 9.37 | 0.23 | 9.17 | 0.24 | 9.17 | 0.20 | 8.96 | 0.27 | 9.37 | 0.24 |
| .41 | 0.25 | 11.00 | 0.28 | 11.20 | 0.33 | 11.20 | 0.27 | 10.19 | 0.30 | 11.20 | 0.28 |
| .63 | 0.28 | 12.83 | 0.32 | | | 12.02 | 0.28 | 11.20 | 0.35 | 12.22 | 0.31 |
| .45 | 0.30 | 14.06 | 0.35 | | | 13.45 | 0.30 | 12.22 | 0.37 | | |
| | | 14.87 | 0.38 | | | 13.85 | 0.35 | | | | |

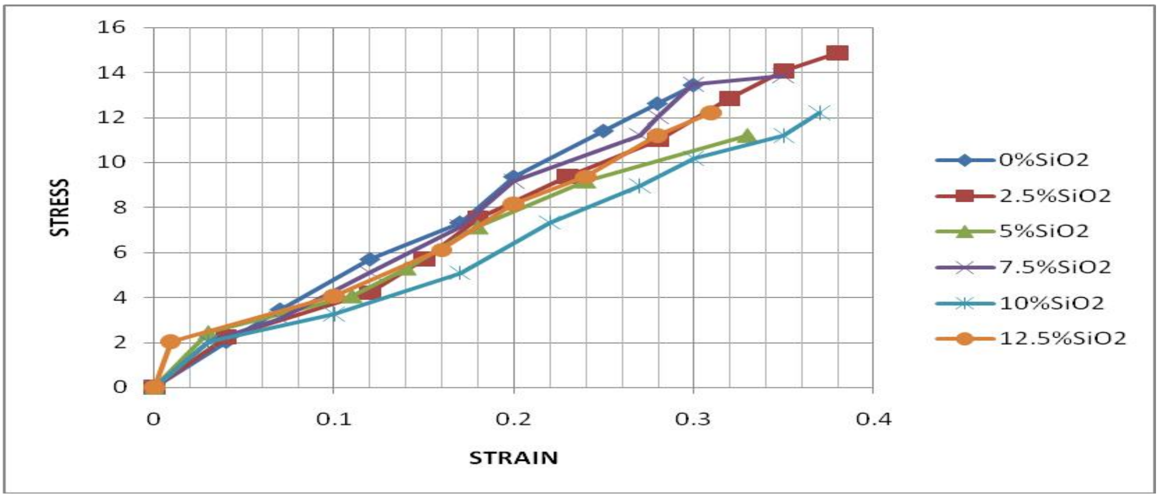


**Figure 6. Compressive Stress-Strain Curve for Al - $SiO_2$ Composites**

**Table 3. PHYSICO-MECHANICAL PROPERTIES OF Al-$SiO_2$**

| Composite Samples (Al.:$SiO_2$) | Vickers Hardness Number (VHN) (10kg) | Compressive Strength (Mpa) | Density, ($g/cm^3$) | Water Absorption capacity (%) |
|---|---|---|---|---|
| 100:0.0 | 6.88 | 13.45 | 2.04 | 2.01 |
| 97.5:2.5 | 8.30 | 14.87 | 2.04 | 1.23 |
| 95.0:5.0 | 8.29 | 11.20 | 2.16 | 1.27 |
| **92.5:7.5** | **8.68** | **13.85** | **2.12** | **0.66** |
| 90.0:10.0 | 6.36 | 12.22 | 2.11 | 1.10 |
| 87.5:12.5 | 6.35 | 12.22 | 2.11 | 1.18 |

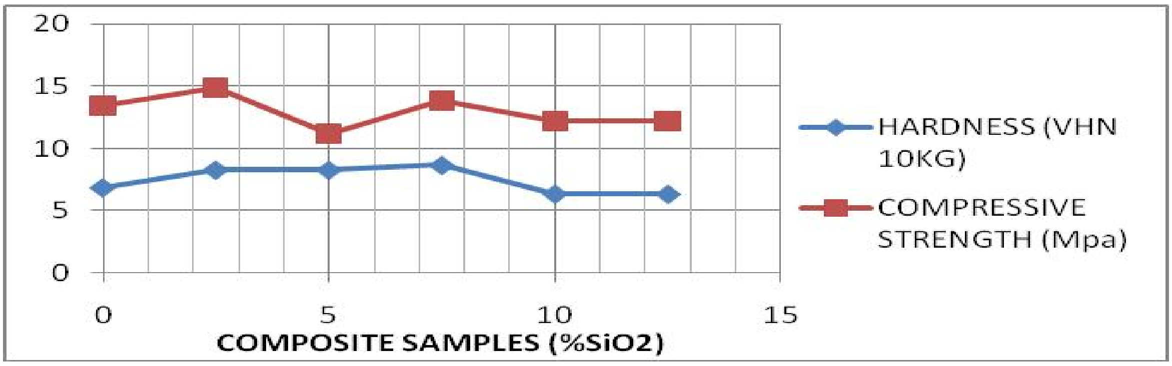


**Figure 7. Hardness and Compression graph for Al - $SiO_2$ Composites**

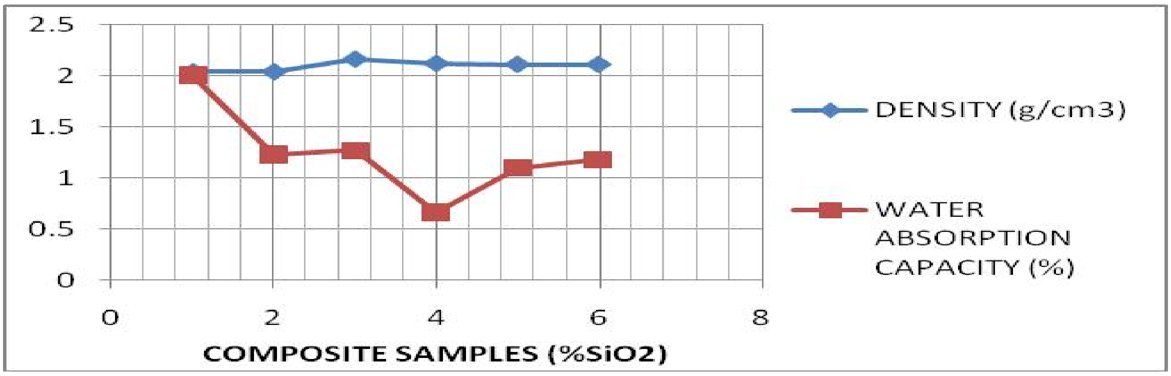


**Figure 8. Density and Water Absorption graph for Al - $SiO_2$ Composites.**

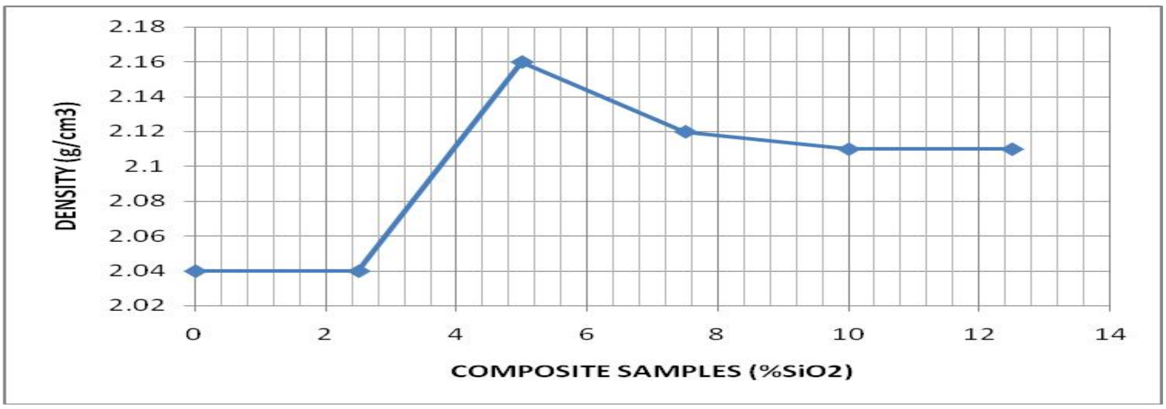


**Figure 9. Density graph for Al - $SiO_2$ Composites.**

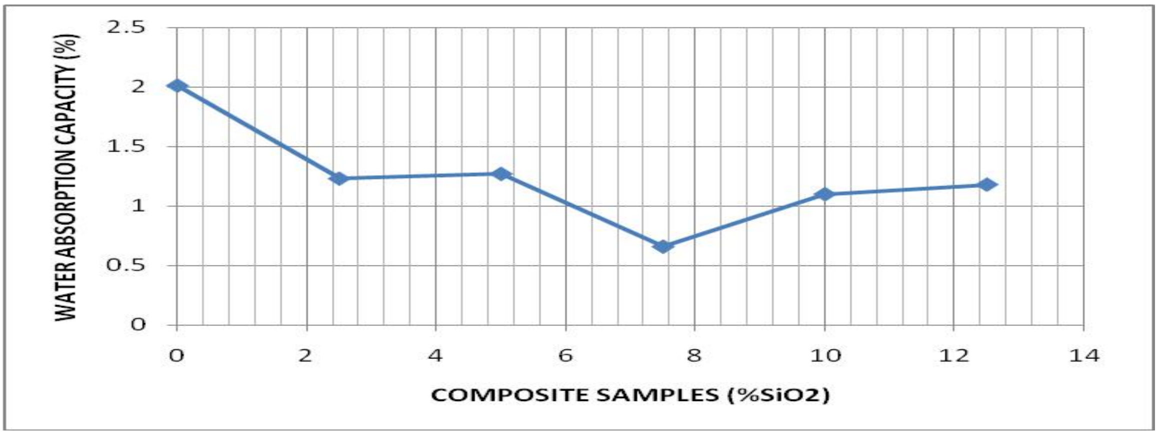


**Figure 10. Water Absorption graph for Al - $SiO_2$ Composites.**

Based on the results obtained above, we may say that the silica reinforcement improved the mechanical properties of aluminum, and that the powder metallurgy process assured a homogeneous distribution of the silica particles in the aluminum matrix.

## 4.0 CONCLUSION

The production of aluminum metal matrix composites reinforced with silica sand was studied in this project. Emphasis was on the determination of its mechanical properties. The powder metallurgy method was employed in studying six different compositions of aluminum and silica: 0%$SiO_2$, 2.5%$SiO_2$, 5.0%$SiO_2$, 7.5%$SiO_2$, 10.0%$SiO_2$, and 12.5%$SiO_2$ respectively. Physical properties such as density and water absorption as well as some mechanical properties like hardness and compressive strength were determined. From the results obtained, the following conclusions could be drawn:

The powder metallurgy process did not only ensure proper homogeneity of the silica reinforcement but also maintained the low density of aluminum. As a material produced by compaction, the rate of water absorption for each compact was also low, with the 7.5% $SiO_2$ reinforcement giving the least absorption. There was an increase in hardness of the composites up to 7.5% $SiO_2$ content, after which a sharp decrease was obtained. The silica reinforcement increased the compressive strength of aluminum, with the 2.5% $SiO_2$ reinforcement giving the highest strength. Aluminum-Silica Composite, using the powder metallurgy method, seems to offer a promising hope in the field of materials science and engineering. The silica reinforcement did not only increase the mechanical properties but also ensured a reduced mass per weight ratio by maintaining the low density of aluminum.

**Acknowledgment.**

The authors express gratitude to the lecturers at the Department of Metallurgical and Materials Engineering and Mechanical Engineering Department of the University of Nigeria, Nsukka for providing the necessary facilities and granting access in the laboratory for this research. The writers acknowledges with gratitude the support of the laboratory staff for their diligent efforts and invaluable contributions. Special thanks go to colleagues and mentors for their feedback.

**Disclosure Statement.**

The authors declare no conflict of interest.

## REFERENCES

[1] Hull, D. and T.W. Clyne (1996), *An Introduction to Composite Materials,* 2nd edition, Cambridge University Press, New York.

[2] Callister, W. D. (2007), *Materials Science and Engineering: An Introduction* John Wiley & Sons, Inc., 6$^{th}$ edition.

[3] Donnell, G.O. and Looney, L. (1991), "Production of Aluminum Matrix Composite Using Conventional PM Technology", J Metallurgy

[4] Taya and Arsenault (1989), "Metal matrix composites", Pergamon press.

[5] Feest, E.A. and Tweed J.H. (1991), *Powder Metallurgy – An Overview*, The Institute of metals Series on Powder Metallurgy. Pg. 267

[6] Gregolin E.N. et al. "Hot Workability and Mechanical Properties of an Aluminum Matrix Composite", Brazil: Department of Metallurgical and Materials Engineering, University of Campinas.

[7] Omah A.D et al. “Mechanical Properties and Microstructure of Some Lead-Free Solders” Journal of Metallurgy and Materials Engineering Vol. 5, Number 2. 2010 pp. 65

[8] E.N.Gregolin et al. “Hot Workability and Mechanical Properties of an Aluminum Matrix Composite”, Brazil: Department of Metallurgical and Materials Engineering, University of Campinas.

[9] A.O. Inegbenebor and F.A. Adeniji. Electrical Insulative Properties of some Agro-waste materials. West Indian Journal of Engineering Vol. 30, No. 1, (July 2007) Technical Paper

[10] Carl Zweben (1998), Composite Materials and Mechanical Design, *Mechanical Engineer’s Handbook*, 2nd ed., Myer Kutz, Ed., JohnWiley & Sons, Inc., New York.

[11] Chawla, K. K. (1998) *Composite Materials Science and Engineering,* 2nd edition, Springer-Verlag, New York.

[12] Ashbee, K. H. (1993), *Fundamental Principles of Fiber Reinforced Composites,* 2nd edition, Technomic Publishing Company, Lancaster, PA.

[13] Woishnis,W. A. (1993), *Engineering Plastics and Composites,* 2nd edition, ASM International, Materials Park, OH.

[14] Friend, C. M. The effect of matrix properties on reinforcement in short alumina fiber-aluminum metal matrix composites, *J. Mater. Sci.* 1987, *22*, 3005–3010.

[15] Ebert, L. J. and Wright, P. K. (1974), Mechanical Aspects of the Interface, in *Interfaces in Metal Matrix Composites*, A. G. Metcalfe (Ed.), Academic Press, New York, p. 31.

[16] Peters, S.T.(1998), *Handbook of Composites,* 2nd edition, Springer-Verlag, New York,.

[17] Agarwal, B. D. and L. J. Broutman (1990), *Analysis and Performance of Fiber Composites,* 2nd edition, Wiley, New York.

[18] Mielke, S., Seitz, N. (1987), *International Conference on Metal Matrix Composites*, The Institute of Metals, London.

[19] Harris, B. (1986), *Engineering Composite Materials*, The Institute of Metals, London.

[20] *Kainer, K. U.* (2006) Basics of Metal Matrix Composites

[21] Clyne, T. W. and Withers, P. J. (1993), *An Introduction to Metal Matrix Composites*, Cambridge University Press, Cambridge.

[22] Kelly, A. and Davies, G. J., The Principles of the Fiber Reinforcement of Metals *Metall. Rev*. 1965, *10*, 1–78.

[23] Jones, W. D. (1960). *Fundamental Principles of Powder Metallurgy*. London: Edward Arnold Ltd.

[24] Zuhailawati, H., Samayamutthirian, P., Mohd, C.H., "Fabrication of low cost of Aluminium Matrix Composites Reinforced with Silica Sand" , Journal of Physical Science, Vol. 18(1), 47-55, 2007

[25] Khan, M. K. (April 1980). "The Importance of Powder Particle Size and Flow Behavior in the Production of P/M Parts for Soft Magnetic Applications". *Intern. J. Powder Metallurgy and Powder Tech.* 16 (2): 123–130

[26] Lide, D. R. (2000). "Magnetic susceptibility of the elements and inorganic compounds". *CRC Handbook of Chemistry and Physics* (81st ed.). CRC Press. ISBN 0849304814

[27] Shakhashiri, B. Z. (17 March 2008). "Chemical of the Week: Aluminum". *SciFun.org*. University of Wisconsin. Retrieved 2012-03-04

[28] Helmboldt, O. (2007). "Aluminum Compounds, Inorganic". *Ullmann's Encyclopedia of Industrial Chemistry*. Wiley-VCH.

[29] Polmear, I. J. (1995). *Light Alloys: Metallurgy of the Light Metals* (3rd ed.). Butterworth-Heinemann. ISBN 978-0-340-63207-9.

[30] Zumdahl, Steven S. (2009). *Chemical Principles 6th Ed.*. Houghton Mifflin Company. p. A22. ISBN 0-618-94690-X.

[31] Lynn Townsend White, Jr. (1961). "Eilmer of Malmesbury, an Eleventh Century Aviator: A Case Study of Technological Innovation, Its Context and Tradition". *Technology and Culture* (Society for the History of Technology) (2): 97–111

[32] F. J. Humphreys, Deformation and annealing mechanisms in discontinuously reinforced metal-matrix composites, *Proc. 9th Risø Int. Symp. On Mechanical and Physical Behavior of Metallic and Ceramic Composites*, S. I. Anderson, H. Lilholt, O. B. Pederson (Eds.), Risø National Laboratory, Roskilde (1988), pp. 51–74.

[33] F. J. Humphreys, A. Basu, M. R. Djazeb, The microstructure and strength of particulate metal-matrix composites, *Proc. 12th Risø Int. Symp. on Materials*

*Science, Metal-Matrix Composites – Processing, Microstructure and Properties*, N. Hansen et al. (Eds), Risø National Laboratory, Roskilde (1991), pp. 51–66.

[34] Strong, A. B., *Fundamentals of Composites: Materials, Methods, and Applications,* Society of Manufacturing Engineers, Dearborn, MI, 1989.

[35] Khairaldin, W.M., Khalil, A.A., Bayoumi. M.R., "Production of Aluminium-Silicon Carbide Composites Using Powder Metallurgy at Sintering Temperature above the Aluminium Melting Point", Journal of Testing and Evaluation (JTE), Volume 35, online published: 3 August 2007.