PROCESSING AND MACHINING OF NANO-Al_2O_3 PARTICLES REINFORCED A356 ALLOY

By

Abdallah Abdelfatah Mohamed Mohamed Abdelkawy

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
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MASTER OF SCIENCE
In

MECHANICAL DESIGN AND PRODUCTION ENGINEERING

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Title of Thesis:

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Key Words:
nanocomposite; MMNC; machinability; ANOVA; RSM**)**

Summary:

In this study, the mechanical and the machinability properties of aluminum-silicon nanocomposites are studied. A356 alloy/2% wt. nanoparticles stir cast samples are poured in different temperatures. Tensile strength, hardness, microstructure, and scanning electron are examined, then the turning process is performed to measure the cutting forces and arithmetical mean value (Ra). The strength and hardness increase because the particles dispersion. The forces and Ra increase with feed and cutting depth. Ra decreases with increasing cutting speed. The nanoparticles increase the cutting forces but produces smoother surface. Statistical analysis used to study the factors and the responses.

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List of abbreviation

MMC	Metal Matrix Composite
MMNC:	Metal Matrix Nano Composite
A356	Aluminum-silicon alloy with 7% silicon
Al_2O_3	Aluminum oxide
ANOVA	Analysis of variance
RSM	Response Surface Methodology
Ra	Arithmetical mean value
d_g	Grain size
d_p	Particle size
v_p	Particles weight fraction
T	Temperature
P	Pressure
μG, μL	The chemical potentials of gas and liquid
ΔS, γ	The change in interfacial energy
γ	Surface energy
LG, SG	Subscripts represent liquid gas, and solid gas
PCD	Polycrystalline diamond
A356/630	A356 conventional alloy stirred at 630℃
A356/700	A356 conventional alloy stirred at 700℃
MMNC/630	MMNC conventional alloy stirred at 630℃
MMNC/700	MMNC conventional alloy stirred at 700℃
SEM	Scanning Electron Microscope.
EDX	Energy-dispersive X-ray spectroscopy
UTS	Ultimate Tensile Strength (MPa)
HRB	Hardness Rockwell Ball
s	cutting speed (m/min)
f	Feed rate (mm/rev)
d	Depth of cut (mm)
T_s	Stirring temperature (℃)
Wt%	Al_2O_3 nanoparticle weight percent
Ra	Arithmetical mean value (μm)
Fv	Main cutting force (N)
Ft	Thrust force (N)
Hp	Horse power
BUE	Built Up Edge
P_s	Specific cutting energy

Abstract

Developing and manufacturing of high strength to weight ratio advanced materials is aimed by many engineers. The main reason for that is to meet challenges in our daily life with increased energy consumption that leads to depletion of energy. The nanocomposites based on the aluminum-silicon alloys have high strength to weight ratio, so, their use in the automotive industry will lead to saving the energy but it is still needed to enhance their mechanical properties.

In this study, the metal matrix nanocomposite (MMNC) of aluminum-silicon alloys as matrix and nanoparticles of alumina as reinforcements was manufactured. Four cast sample conditions were prepared by stir casting technique. The conditions were A356 alloy poured in both state sub liquidus line, and state above liquidus line, A356 reinforced with 2% weight of Al_2O_3 nanoparticles and poured in both state sub liquidus line, and state above liquidus line. The tensile strength, ductility, hardness were measured for the samples and microstructure features were examined for the four conditions. Then, the turning operation performed on the center lathe for A356 alloy and nanocomposite A356/Al_2O_3 that were poured in state above liquidus and nanocomposite A356/Al_2O_3 that was poured in state sub liquidus. Cutting forces and the surface roughness were measured.

The tensile strength increased with approximately 10% for nanocomposite poured in state sub liquidus, and approximately 22% for nanocomposites poured in state above liquidus with respect to conventional alloy poured in state above liquidus due to dispersion of Al_2O_3 hard ceramic particles in the matrix. The hardness of MMNC was higher than that of A356 alloys. The dendritic microstructure in state above liquidus transformed to globular grains in state sub liquidus. It was found that the main cutting forces for nanocomposite poured in state above liquidus were higher than that for monolithic alloy at the same pouring state, and the nanocomposite that poured in state sub liquidus due to increase the shear strength because of the dispersion of the nanoparticles and pouring in state above liquidus. The addition of nanoparticles and stirring temperature had no effect on the thrust force. The addition of nanoparticles improved surface roughness because increasing the hardness of the nanocomposite. The cutting forces increased with increasing feed rates and depth of cut but the cutting speed had little effect on the cutting force. The surface roughness (Ra) increased with increasing feed rates and depth of cut but it decreased with increasing the cutting speed.

The analysis of variance (ANOVA) technique was used to define the significant factors on tensile strength, hardness, cutting forces, and surface roughness. Feed rates, cutting speeds, and depth of cut have significant effect on cutting force and surface roughness. Nanoparticles and pouring state have a significant effect on main cutting force and surface roughness but they do not reach to significant level in case of thrust force. Repose surface methodology (RSM) was used to build models in the thesis results domain to correlate cutting forces and surface roughness with cutting conditions, pouring temperature and nanoparticles percent 2%.

Finally, addition of nanoparticle to aluminum alloy improves the tensile strength, ductility and surface roughness but increases the cutting forces.

Chapter 1 : Introduction

1.1. Back ground.

The material is one of the most important arms in the engineering field and industrial revolution. So, the development of the materials properties is the goal of researchers. From the beginning of the history the human discovered the metals like the iron, aluminum, and copper. The fuel consumption is directly related with the weight of the automotive. In the beginning, the steel and cast iron were the dominant materials in the automotive industries. But with the increasing the global power problem, the research to find high strength to weight ratio materials becomes in the first priorities of many researchers.

The alloys of aluminum and magnesium are the candidates to use instead of the iron alloys. Aluminum is the metallic element with the symbol Al with the atomic number 13 and atomic weight 27. Aluminum is the third element in the earth's crust after oxygen and silicon. It is about 8% of the mass of the earth's crust. Pure aluminum is weak but it has high thermal and electrical conductivity so, it used in electrical conductor and for domestic products such as pans, cans, packaging so to use aluminum in heavy duty products must be alloyed. Because of the physical properties of aluminum it is preferable for many applications. The aluminum and its alloys are lighter than steel, good electrical transmission, and low melting point that gives very good merit for aluminum in casting process (castability)[1].

Aluminum-silicon alloys are important alloys, where they are used many applications as automotive cylinder blocks, pistons and military applications. The importance of Aluminum- silicon (Al-Si) comes from their good wear resistance, high strength and hardness and low thermal expansion [2]. Where the aluminum alloys cylinder blocks are lighter than cast iron cylinder blocks by 40%. So, the demand of cars having light aluminum blocks was 60% of European cars in 2003 [3]. The aluminum alloys are considered as promising material in automotive industries. The graph in fig 1.1 shows the global aluminum use and the prediction to use, where the figure shows increasing in use of aluminum in automotive industries [4].

Metal matrix composite (MMC) is defined as a material manufactured form two or more materials to obtain tailored properties as strength, hardness, stiffness, corrosion resistance and others [5]. Metal Matrix Composites (MMC) with aluminum based alloys have high modulus of elasticity, strength, hardness, wear resistance and improved thermal stability. The reinforcements in MMC are in different sizes. Reinforcing the aluminum-silicon alloys with micron and nanoparticles is a method for increasing the strength of the alloy at nearly the same weight.

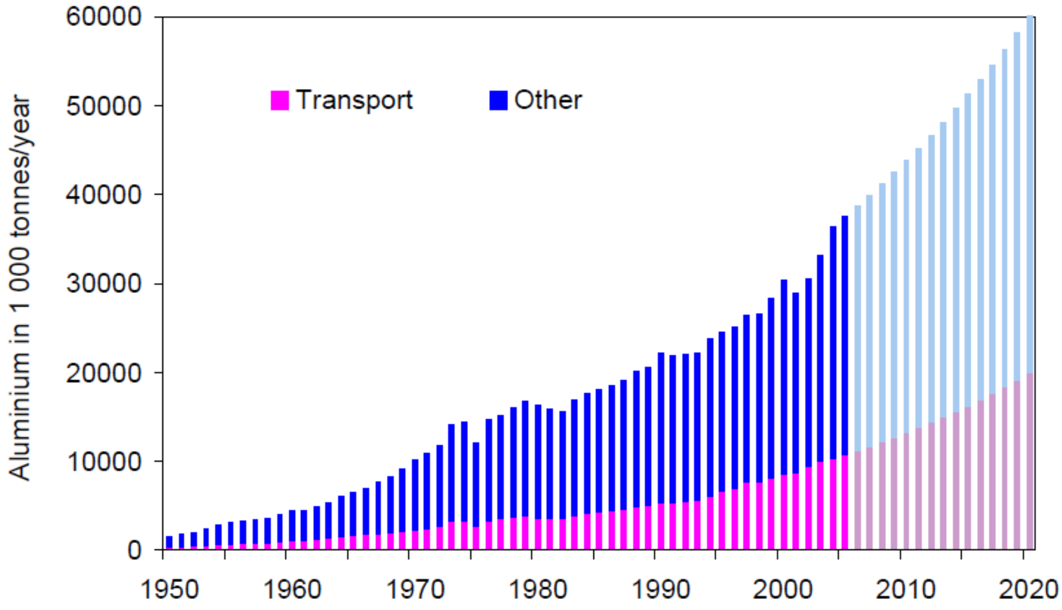

Figure 1. 1: The global aluminum use and prediction (1950 to 2020)[4].

The machining is a main process in cylinder block and many other applications of the MMC. Machinability is a property for material measured by tool life, cutting forces, surface roughness and conducted temperature [6].

The aim of this thesis is reducing the weight of cylinder blocks by using lighter material have high strength to weight ratio to reduce vehicle consumed fuel. The reinforcing the aluminum-silicon alloys with the hard ceramic nanoparticles is the used technique to enhance the aluminum-silicon alloys properties.

The main manufacturing process in cylinder block industries are casting and machining. In this thesis, MMNCs were processed then the mechanical and metallographic features are examined. Where the ultimate tensile strength, ductility, and hardness were tested. The cutting forces for metal matrix nanocomposite (MMNC) of hypoeutectic aluminum-silicon alloy and alumina (Al_2O_3) are very important to decide the machining and cutting tool requirements and the surface roughness of the bore of cylinder block and pistons have a major effect on fuel combustion and reduce harmful exhaust emission.

Chapter 2 : Literature Review

2.1. Introduction

This chapter reviews related topics about cylinder blocks made form aluminum alloys, the aluminum-silicon alloys phase diagram, the manufacturing technologies of metal matrix composites, the machinability measures, the machinability of metal matrix composite with aluminum silicon matrix, and the statistical analysis methods used for machinability measures. The main covered topics are:

1- Engine cylinder blocks materials.
2- Aluminum-Silicon alloys.
3- Metal Matrix Nanocomposite (MMNC) technologies.
4- Machinability measures and the machinability of MMC.
5- Statistical analysis methods.

2.2. Engine cylinder block

The automotive materials must fulfil several criteria to be approved. Some of these criteria are required for environmental and safety regulations. The general requirements in automotive industry are [7]:

1- **Lightweight**, reducing the weight has environmental and economy benefits. Where, 10% reduction in weight leads to reduce the fuel consumed with 7% and reducing one kilogram of vehicle weight reduces the carbon dioxide with 20kg in vehicle life.

2- **Cost**, is one of the most important factors in automotive industry. Cost includes: cost of raw materials, cost of manufacturing, cost of design and cost of product test. Aluminum and magnesium alloys are more costly than cast iron and steel as raw material but, aluminum and magnesium alloys manufacturing is less costly due to reducing manufacturing cycle time because of less melting temperature, better machinability compared to cast iron and steel, ability to have thinner sections due to good fluidity, closer dimensions, and near net shape products.

3- **Safety**, there are two important concepts in safety in automotive industry that have to be considered, crashworthiness and penetration resistance. Where crashworthiness is the ability to absorb impact energy and survive the passenger. Penetration resistance is the total absorption without allowing projectile or fragment penetration. The current regulation in automobiles design is that when the automobile impacts with a solid immovable object at 15.5 m/s, the resulting force on passenger should not exceed 20g [7].

Using material with high strength to weight ratio can meet all above requirements. Where using this material reduces the weight of the cylinder block without losses in the strength that leads to reduce the fuel consumption and exhausts emissions. Where the engine block that is the housing of all other components and the largest weight component