Abstract

Metal matrix composite (MMCs) are next generation materials. MMCs add higher strength and stiffness than the matrix alloy, excellent wear resistance and lower coefficient of thermal expansion (CTE). Additional functionalities can be designed into some MMCs through appropriate selection of constituents. One of the important objectives of metal matrix composites is to develop a material with a judicious combination of toughness and stiffness. It decreases the sensitivity to cracks and flaws and at the same time increases the static and dynamic properties. The reinforcement effect occurs due to the extraordinary high strength of whiskers with diameters below a few micrometers.

In general, Metal matrix composites consist of at least two components. One is the metal matrix and the second is reinforcement. In all cases, the matrix is defined as a metal, but a pure metal is rarely used as the matrix. It is generally an alloy. In the productivity of the composite, the matrix and the reinforcement are mixed together. Matrices based on Ag, Al, Cu Mg, Ni and Ti are all commercially produced and used. Discontinuously reinforced (DRA) aluminium (Al) accounts for 69% of the annual MMC production by mass.

Reinforcements most often used in commercial applications are Al₂O₃, B₄C, and SiC. The reinforcement of largest commercial volume is SiC by a significant margin, followed by Al₂O₃ and TiC. Nearly, all MMCs in commercial use rely on discontinuous reinforcements, although applications exist for MMCs with continuous graphite, SiC and Al₂O₃ fibers. MMCs offer advantages such as light in weight, high stiffness, stability at
high temperature and good wear resistance. MMCs find applications in the ground transportation (auto and rail), aerospace, industrial, recreational and infrastructure industries.

The most common particulate composite system is an aluminum alloy (AA) reinforced with silicon carbide (SiC). So far most of the alloys that have been chosen as matrices are A356, 2000 and 6000 series alloy. Few studies have been reported on the AA7000 series alloys reinforced with silicon carbide particulate. These alloys show the highest strength of commercially available Al alloys and are widely used for structural applications. 7075 Al alloy possess lightweight and excellent properties as structural materials which can be optimized with SiCp addition and a good fabrication technique. So, 7075 Al alloy reinforced with different percentage of SiC particles has been selected as the material for research work.

Fabrication of composite requires incorporating a stiff second phase as a load bearer in a compliant and ductile matrix. Their greatest asset is the large variety of properties offered in combining many possible matrices and reinforcements. This allows changing material properties to meet specific and challenging requirement. MMCs can be fabricated by various routes such as stir casting process, spray deposition process and mechanical alloying. Each technique is suitable for particular combinations of ingredient. Mechanical properties of MMCs are decided by ingredients and fabrication techniques.

The process of stir casting generally involves the admixture of ceramic particulate reinforcement with a molten metal matrix. The particulates are distributed and suspended in the molten metal via high energy mixing or another appropriate process. Particle distribution in the matrix material during the melt stage of casting process depends
strongly on the stirring speed, heating temperature, stirring time, particle wetting, effectiveness of mixing and minimizing of gas entrapment. The uniformity of particle dispersion in a melt before solidification is also controlled by the dynamics of particle movement in an agitated vessel. Continuous stirring of the melt with a motor driven agitator is essential to prevent settling of particles. The suspended material is then cast as a foundry ingot, extrusion billet or rolling bloom. Chemical reactivity and reinforcement size and density are important considerations. Products with volume fraction \( V_f \) ranging from 10% to 40% can be provided by this process. This process is widely used for applications that require high production volumes and low cost. Hence, stir casting has been identified as process for fabrication of AA7075/SiC composites.

Examination of microstructure of AA7075/SiC composite by optical and scanning electron microscopy (SEM) is necessary to study uniform SiCp distribution into 7075 Al alloy matrix. SiC reinforcements tend to react with aluminum during processing, leading to the formation of \( \text{Al}_4\text{C}_3 \) and Si at the interface. Presence of secondary chemical reactions (formation of \( \text{Al}_4\text{C}_3 \)) is detected by electron probe microscopic analysis (EPMA) and XRD analysis. Differential thermal analysis (DTA) is carried out to confirm the onset temperature of reactions. Micro yield phenomena during thermo cycling of AA7075/SiC composite due to mismatch of the thermal expansion coefficients of the matrix and the SiC particles are studied by thermo mechanical analysis (TMA). Only few works have been reported in literature about analysis of 7075 Al alloy using one of these techniques. A complete analysis of AA7075/SiC composites using these techniques is not available in literature. These analyses have been identified to ensure that SiC particles are uniformly distributed in AA7075/SiC composite. This structure is free from any kind of
defects/ porosity and there are no adverse chemical reactions. Then, only AA7075/SiC composite will be useful.

In order to achieve optimum properties, the distribution of the SiC particles in the 7075 aluminum alloy must be uniform and the bonding between these two substances should be optimized. The mechanical properties of MMCs are controlled to a large extent by the structure and properties of the SiC reinforcement and 7075 aluminum alloy interface. A stronger interface permits transfer and distribution of load from the matrix to the reinforcement, resulting in an increased elastic modulus and strength.

SiC particles with 7075 aluminium matrix are harder than tungsten carbide (WC), which pose many problems in machining. Machining of aluminium alloy/SiC composites is one of the major problems, which resist its wide spread engineering applications. From some early conventional turning tests on Al/SiC MMCs, it is found that the tool wear is excessive and surface finish is very poor while carbide tip tools are used for machining. The hard SiC particles of Al/SiC-MMC intermittently come into contact to the hard surface. These particles act as small cutting edges like those of a grinding wheel on the cutting tool edge which in due course is worn out by abrasion and resulting in the formation of poor surface finish during turning. So far no process has been reported for machining of AA7075/SiC composites. So, there is a need to develop a process for machining of AA7075/SiC composites. This process includes identification of machines viz lathe and CNC turning machine, cutting tools like carbide insert and planning and techniques for experimentation viz pilot experiments, experiments according to response surface methodology and confirmation experiments.
Optimization of machining/process parameters is necessary as it not only increases the utility for machining economics, but also the product quality to a great extent. In recent years, desirability function approach is used by some of the researchers for finding the optimal solutions using multi performance objective. Genetic algorithm is considered to be one of the best optimization techniques because the optimal solution obtained from GA technique is most likely to be a global solution.

The present research has been undertaken with a main objective to overcome the problems during fabrication, characterization and machining of AA7075/ SiC composites. The research work has been focused on the following aspects:

i. Fabrication of 7075 Al alloy with 10wt%, and 15wt% of SiC particulate (Particle size 10 - 20 µm and 20 - 40 µm) composites with minimum porosity.

ii. Microstructural examination by optical microscope and scanning electron microscope to study the proper distribution of grains.

iii. Characterization viz EDX, EPMA, DTA, XRD and TMA of 7075 Al alloy, AA7075/10wt%SiCp and AA7075/15wt%SiCp composites.

iv. Carry out tests to find out mechanical properties like tensile strength, compressive strength and hardness.

v. CNC Turning machine performance evaluation using Design of experiments. (Response Surface Methodology)

- Analyzing the effect of machining/process parameters (cutting speed, feed, depth of cut, and nose radius of tool) on surface roughness, tangential
force, feed force, radial force, power consumption, flank wear and crater wear.

- Understanding the behavior of tungsten carbide insert in machining of 7075 Al alloy and AA7075/SiCp composites.
- Analyzing the effects of different cutting conditions on tool-life/ tool wear.

vi. Optimization of machining/process parameters by desirability function to minimize surface roughness, tangential force, feed force, radial force, power consumption, flank wear and crater wear and to maximize tool-life.

vii. Multi objective optimization by desirability function to minimize surface roughness, tangential force, feed force, radial force, power consumption, flank wear and crater wear and to maximize tool-life.

viii. Experimental validation of results.

ix. Optimization of process parameters by using genetic algorithm tool box in MATLAB.

x. Comparison of optimization results obtained by desirability analysis and genetic algorithm.

The thesis is organized as follows:

**Chapter 1:** Chapter 1 deals with the introduction about the metal matrix composites, needs, advantages and applications of metal matrix composites and about thesis work. Reasons for selection of 7075 Al alloy as matrix, SiC particles as reinforcement are discussed. The problems being faced in machining of AA7075/10SiCp and need to develop a process for machining is also explained.
Chapter 2: Chapter 2 presents the review of published literature on fabrication, characterization, machining, modeling and optimization of machining parameters and multi characteristic optimization. Gaps have been identified in literature review and are discussed.

Chapter 3: Chapter 3 deals with need of this investigation, objectives of present investigation, work plan. The different phases of work plan have been explained.

Chapter 4: Chapter 4 deals with fabrication, characterization and investigation of mechanical properties of 7075 Al alloy and AA7075/10 wt% SiC (particle size 10-20µm), AA7075/15 wt% SiC (particle size 10-20µm), AA7075/10 wt% SiC (particle size 20-40µm) and AA7075/15 wt% SiC (particle size 20-40 µm) composites, selection of machines and measurement of different quality characteristics of machined parts (surface roughness, cutting forces, Power Consumption, flank wear, crater wear and tool life) of Aluminium Alloy-SiC Particle Composites and evaluation criteria. Design of experiments is also included.

Chapter 5: The results regarding, fabrication, microscopic examination, EDAX, EPMA, DTA, XRD, TMA, Young’s Modulus and Peak Frequency, Tensile test, Compression test Hardness test are presented.

Chapter 6: Experimental results of eight different responses viz surface roughness, tangential force, feed force, radial force, power Consumption, flank wear, crater wear and tool life; during machining of AA7075/ SiC composites are presented.
Chapter 7: Results obtained by optimization of machining parameters by desirability analysis and genetic algorithm are presented. Multi objective optimization is also included.

Chapter 8: Results presented in chapter 5, 6 and 7 are discussed here. It is possible to carry out machining of AA7075/10 wt% SiC (particle size 10-20\(\mu\)m), AA7075/15 wt% SiC (particle size 10-20\(\mu\)m), AA7075/10 wt% SiC (particle size 20-40\(\mu\)m) and AA7075/15 wt% SiC (particle size 20-40\(\mu\)m) composites. Desirability analysis and genetic algorithm are effective techniques for finding the optimum solutions. Effects of process parameters on responses have been discussed.

Chapter 9: It contains the conclusions of the research work conducted in this thesis. Finally chapter concludes with scope of further work.