



Correlation of Tensile and Hardness of Dual Particle and Triple Particle Reinforced Al-7075/ Al₂O₃ Metal Matrix Composite

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Abstract : In this work the study on hardness, tensile and wear behaviour of dual particle and triple particle size Alumina (Al₂O₃) reinforced aluminium alloy based metal matrix composite (Al₂O₃-Al MMC) was carried out. Al-MMCs were prepared using 10 vol% Al₂O₃ reinforcement into aluminium metal matrix and developed using stir casting process. Stir casting is a primary process of composite production whereby the reinforcement ingredient material is incorporated into the molten metal by stirring. The Dual particle and Triple particle composite consists of Al₂O₃ in four different sizes i.e. coarse, intermediate, fine and super fine (210μ, 180μ, 80μ & 10μ). The hardness test was carried out using Vickers Hardness Tester and Brinell Hardness Tester. Tensile test was carried out on a Universal Testing Machine (UTM).

The test results showed that Dual particle composite and triple particle composite exhibited better hardness compared to as cast AL-7075. Tensile Strength of Triple particle reinforced MMC was found to be higher than that of dual particle reinforced composite material.

Index Terms - Dual Particle, Triple Particle, Stir Casting Al 7075, Al₂O₃, Wear rate.

I. INTRODUCTION

Aluminum alloys are preferred engineering material for automobile, aerospace and mineral processing industries for various high performing components that are being used for varieties of applications owing to their lower weight, excellent thermal conductivity properties. Among several series of aluminum alloys, heat treatable Al-6061 and Al-7075 are much explored, among them Al-6061 alloy are highly corrosion resistant and are of excellent extricable in nature and exhibits moderate strength and finds much applications in the fields of construction (building and high way), automotive and marine applications.

Aluminum alloy Al7075 possess very high strength, high toughness and are preferred in aerospace and automobile sector. The composites formed out of aluminum alloys are of wide interest owing to their high strength, fracture toughness, wear resistance and stiffness. Further these composites are of superior in nature for elevated temperature application when reinforced with ceramic particle.

In recent years many processing techniques have been developed to prepare particulate reinforced metal matrix composites. These techniques are stir casting, liquid metal infiltration, squeeze casting, spray co-deposition, powder metallurgy etc. Among the variety of processing techniques available for particulate or discontinuous reinforced metal matrix composites, stir casting is one of the methods accepted for the production of large quantity composites. It is attractive because of simplicity, flexibility and most economical for large sized components to be fabricated.

II. EXPERIMENT

Several factors have to be considered in design and development of the composite material. The efficiency of the composite material depends on the matrix and reinforcement. Excess reinforcement in the matrix will result in poor mechanical properties. The chemical compatibility of the reinforcement with matrix material has to be considered in designing the composite system.

Table 2.1: Composition and Properties of AL-7075

| Element | Si | Fe | Mn | Mg | Cu | Zn | Ti | Cr | Al |
|----------|-----|-----|-----|-----|----|-----|-----|------|-------|
| Weight % | 0.4 | 0.5 | 0.3 | 2.9 | 2 | 6.1 | 0.2 | 0.28 | 87.32 |

| Mechanical property | Value |
|---------------------------|----------|
| Hardness –Brinell | 150 |
| Ultimate tensile strength | 572 MPa |
| Tensile yield strength | 503 MPa |
| Elongation at beak | 11% |
| Modulus of Elasticity | 71.7 GPa |
| Poisson's ratio | 0.33 |
| Fatigue strength | 159 MPa |
| Machinability | 70% |

The aluminum alloy Al-7075 has been selected as the matrix material. It is compatible with the reinforcement and has good mechanical property and castability at the alloy level itself. The material also has good response to age hardening, heat treatment process and precipitation hardening.

The reinforcement alumina (Al₂O₃) is in the form of particle size 10 micron to 210 micron. It is more stable with aluminum and withstands high temperature. It is an oxide ceramic having low affinity to oxygen to form oxides. The particulate form of the reinforcement has better distribution in the matrix to provide isotropic property for the composite. The properties of the alumina are as shown in table 2.

Table 2.2: Properties of Al₂O₃

| Property | Value |
|---|-------|
| Melting Point°C | 2072 |
| Hardness(kg/mm ²) | 1175 |
| Density(g/cm ³) | 3.95 |
| Coefficient of thermal expansion(micron/ m°C) | 8.1 |
| Fracture Toughness | 3.5 |
| Poisson's ratio | 0.21 |
| Colour | White |

The amount of reinforcement to be dispersed in the matrix medium is selected as 10%. The quantity of reinforcement was calculated on volume fraction basis. To determine the quantity of the reinforcement following mathematical relation was used:

$$R_w = \frac{f \times \rho_r}{f \times \rho_r + (1-f) \times \rho_m} \quad 2.1$$

Where,

R_w = Weight of reinforcement, f = Volume fraction of reinforcement, ρ_r = Density of reinforcement, ρ_m = Density of matrix

Table 2.3: Specimen Composition for varying weight fraction.

| Particle Type | Al-7075 | 10 μ m | 80 μ m | 180 μ m | 210 μ m |
|--------------------|---------|------------|------------|-------------|-------------|
| Dual particle -1 | 2150g | 175g | | | 175g |
| Dual Particle -2 | 2150g | | 175g | 175g | |
| Triple particle -1 | 2150g | | 87.5g | 87.5g | 175g |
| Triple particle-2 | 2150g | 175g | | 87.5g | 87.5g |

To prepare the dual and triple particle composites, reinforcements had to be selected in various combinations. Table 3.3 shows the combination of reinforcement particles mixed in the matrix to develop the composites.

III. COMPOSITE DEVELOPMENT

The matrix material Al-7075 was obtained in the form of rectangular billet of 20mm x 10mm area and length 50mm. The bars are cleaned to remove the impurity, dust and oil and heated in graphite crucible in electric furnace. The quantity of alumina and the reinforcement are shown in table 3. The furnace temperature was held at 900°C, the melting temperature at 800°C. The reinforcement was heated separately at 450°C. The constant stirring of the melt carried out with alumina stirrer to get uniform distribution of the ceramic particles. The stirring was carried out for 10 minutes and the melt was poured into a rectangular metal mould measuring 160x160x20 mm.



Fig 3.1. Casting of the composite material

IV. CHARACTERIZATION

Microstructure of the material as determined by any of the available microscopic techniques including reflected light metallography and scanning electron microscope (SEM). The microstructure analysis reveals the distribution of reinforcement in the matrix. Uniform distribution of the reinforcement in the matrix is vital to obtain material isotropy and it can be observed in the microstructure analysis.

Vickers Hardness Test was conducted according to ASTM E384 standards. Vickers testing is divided into two distinct types of hardness tests: macro indentation and micro indentation tests. These two types of tests are defined by the forces. Micro indentation Vickers (ASTM E 384) is from 1 to 1000 gf and macro indentation ranges with test forces from 1 to 120 kgf as defined in ASTM E 92.

Table 4.1: Vickers Hardness Test Values

| Sl. No | Specimen | Applied Load (kg) | Length of Diagonal "D1"(mm) | Length of Diagonal "D12" (mm) | Average length of diagonal "d" (mm) | VHN |
|--------|------------------|-------------------|-----------------------------|-------------------------------|-------------------------------------|--------|
| 1 | DP-1 | 20 | 0.560 | 0.556 | 0.558 | 119.08 |
| 2 | DP-2 | 20 | 0.558 | 0.553 | 0.555 | 120.37 |
| 3 | TP-1 | 20 | 0.557 | 0.543 | 0.555 | 122.57 |
| 4 | TP-2 | 20 | 0.513 | 0.582 | 0.5475 | 123.70 |
| 5 | Al7075 (As Cast) | 20 | 0.652 | 0.658 | 0.655 | 86.28 |
| 6 | Al 7075 T6 | 20 | 0.455 | 0.454 | 0.4545 | 179.5 |

Tensile test is vital to understand the behaviour of the composite material, i.e. ductile or brittle nature of the MMC. In the present study, a rectangular billet measuring 30x30x20 mm was machined into a tensile specimen. The dimensions are as shown in the figure 4.5. The specimen was tested in a FIE Universal Testing Machine of 20 ton capacity. The tensile test was conducted to determine the Ultimate stress and elongation of the specimen at peak load.

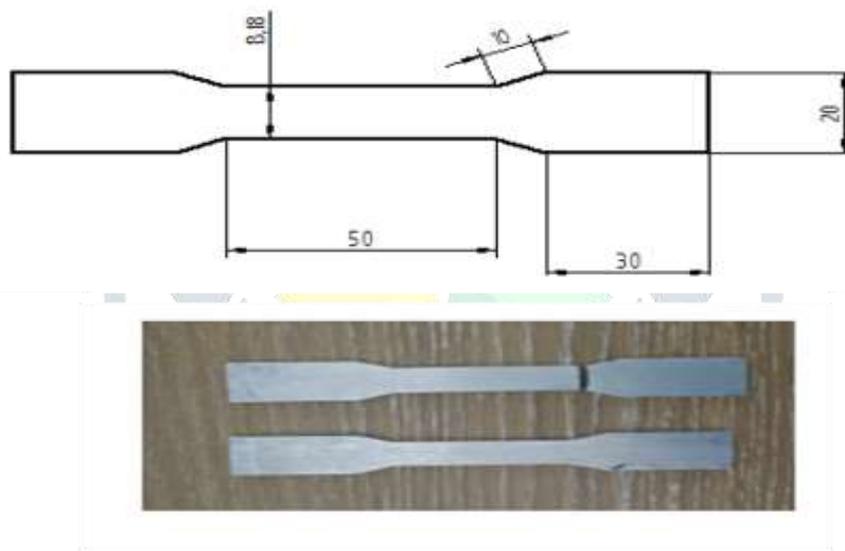


Fig 4.1. Casting of the composite material

The values of Tensile test has been carried out on the flat specimen as per standards and the results of the test are shown in table 4.2 for dual particle and triple particle reinforced specimens.

Table 4.2: Tensile test results

| Sl. No | Specimen | Peak Load N | Ultimate stress N/mm ² | Maximum Displacement mm | % elongation |
|--------|----------|-------------|-----------------------------------|-------------------------|--------------|
| 1 | DP-1 | 20 | 0.560 | 0.556 | 0.558 |
| 2 | DP-2 | 20 | 0.558 | 0.553 | 0.555 |
| 3 | TP-1 | 20 | 0.557 | 0.543 | 0.555 |
| 4 | TP-2 | 20 | 0.513 | 0.582 | 0.5475 |

V. RESULTS AND DISCUSSION:

Optical micrograph is shown in the fig 5.1 which clearly reveals distribution of reinforcement Al_2O_3 for all the casting under investigation. Dendritic structure can be observed which is due to many factors like thermal conductivity mismatch, melting temperature etc. Stirring action also influence the dendritic growth.

The optical micrograph for dual particle reveals more uniform distribution compared to triple particle. Little particle clustering is observed at some places due to imperfect wetting during addition of particles. Here, the air gets trapped in the melt without being able to escape due to the increased viscosity of the melt during the particle additions.

The presence of alumina in the Al 7075 affects the dendrite structure. Similar findings are reported by various researchers. The clustering may also be caused by the accumulation of Al_2O_3 particles in the liquid between the growing dendrites, which seems to inhibit continued dendritic growth.

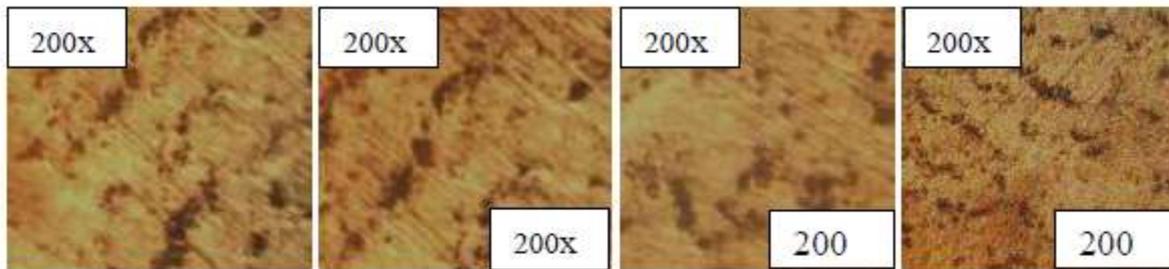


Fig 5.1: Microstructure of DP-1

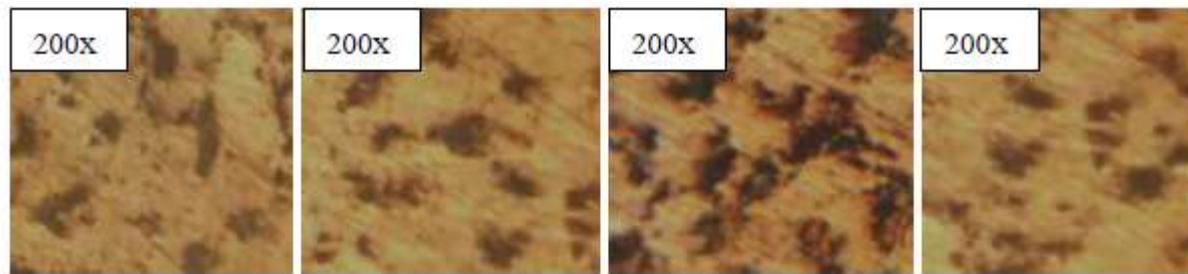


Fig 5.2: Microstructure of DP-1

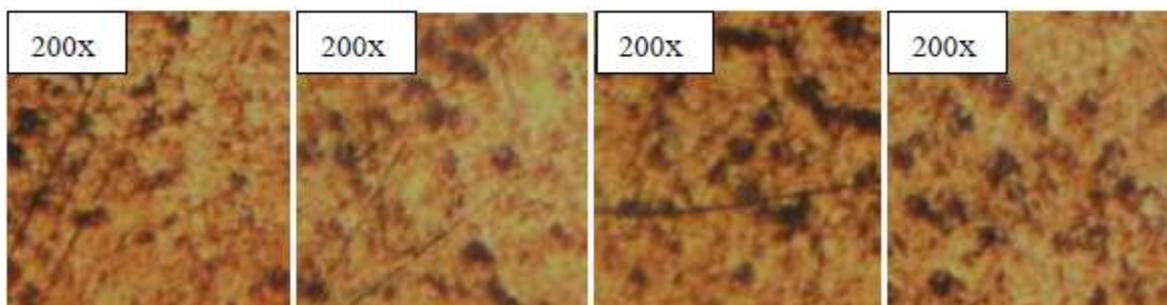


Fig 5.3: Microstructure of TP-1

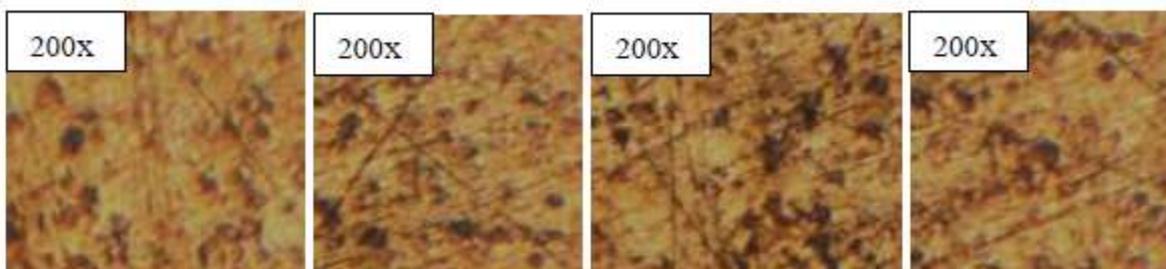


Fig 5.4: Microstructure of TP-2

The micrograph shown in figure 5.1 indicates dual particle reinforced composite has uniform distribution of reinforcement than triple particle. Clustering of the particle are more in triple particle-2 due to sub-micron particle present ($10\mu m$). Coarse particle produces uniform distribution compared to coarse and fine particle. Overall structure indicates presence of alumina particles in the matrix which leads to better Tribological and mechanical properties of composites.

Scanning electron micrograph of composites is shown in the figure (5.5, 5.6, 5.7 & 5.8). The matrices of all specimens exhibit a combination of primary columnar dendritic grains and equiangular grains. The reinforcement particles are distributed uniformly on grey scale. The particles added externally into the melt remains as it is (Al_2O_3). With higher magnification the Al_2O_3 is visible as irregular shaped particles.

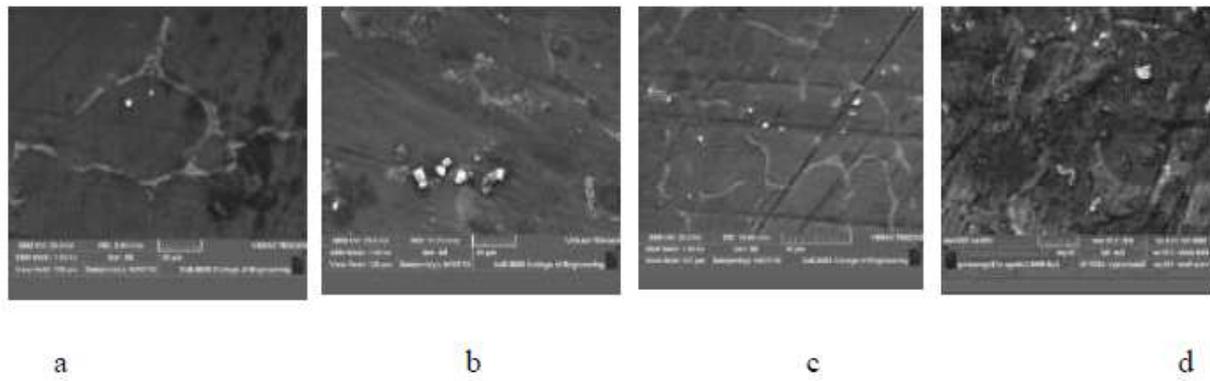


Fig 5.5. SEM Micrograph of a)DP-1, b) DP-2, c) TP-1, d) TP-2.

The composite hardness is measured in as cast condition which is lower than hardness of Al 7075-T6 as seen in the fig (5.8 & 5.9). But when comparing with hardness of as cast 7075 aluminium alloy nearly 30% increase in hardness value can be observed. Therefore heat treating the composite material will increase the hardness further as compared to Al 7075-T6. Hardness also depends on interfacial boundary between the matrix and the reinforcement.

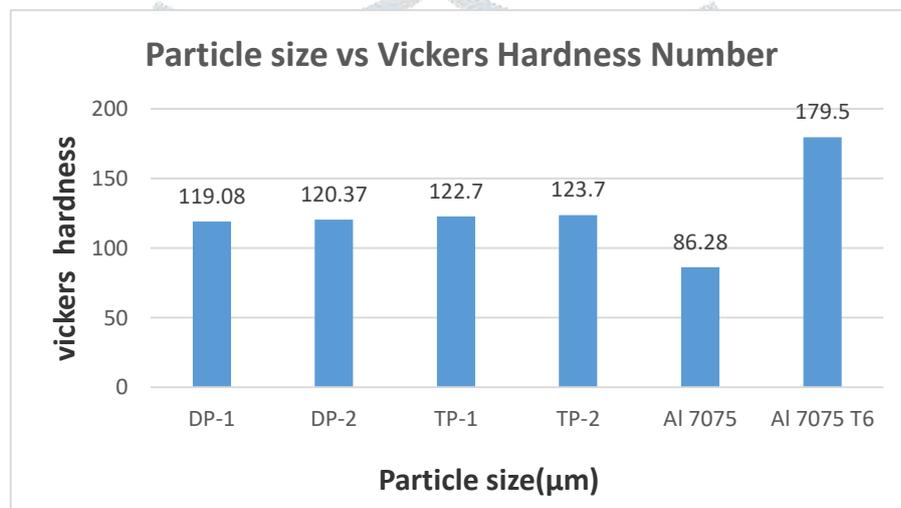


Fig 5.6 Particle size vs Vickers Hardness Number

Density of the composite material calculated theoretically and experimentally is shown in the figure 5 the values are close to each other with only 5%-7% porosity. It indicates good casting with no inclusions and air bubbles in the castings. The figures 5 show the range of density as well as the porosity of all the specimens with the as-cast and T6 Al7075.

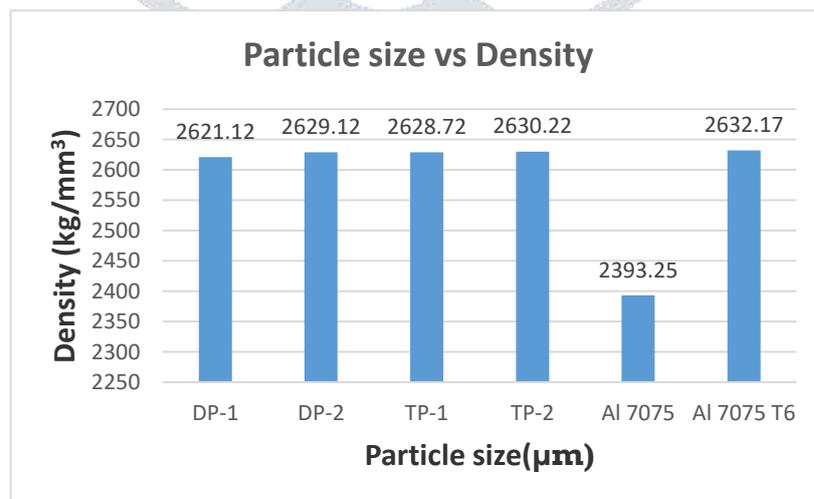


Fig 5.7. Particle size vs Density

The figure 5.13 indicates tensile strength variation with respect to particle size. It can be observed that triple particle reinforced composite shows higher tensile strength compared to dual particle, comparing the values of tensile strength of composites with Al 7075-T6 it indicates decrease in tensile strength of composite which is in agreement with several reports in which composite manufactured by stir casting.

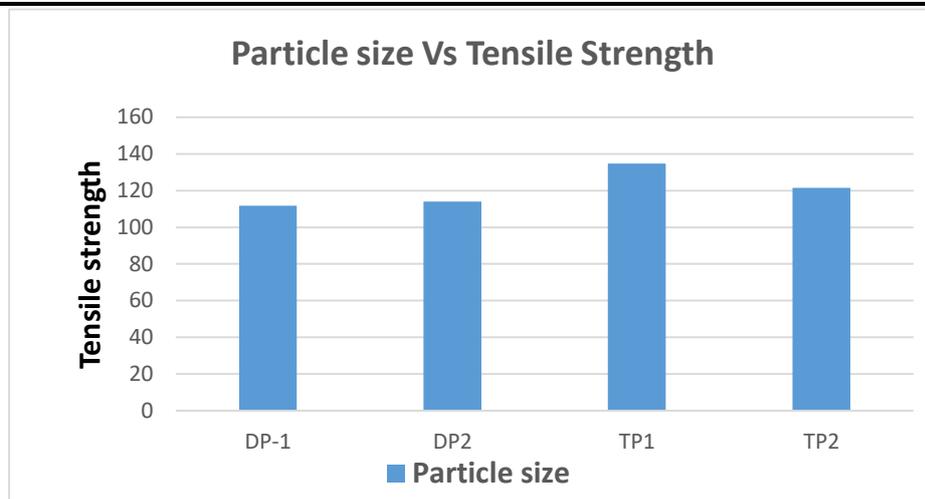


Fig 5.8 Tensile strength variation with Particle size

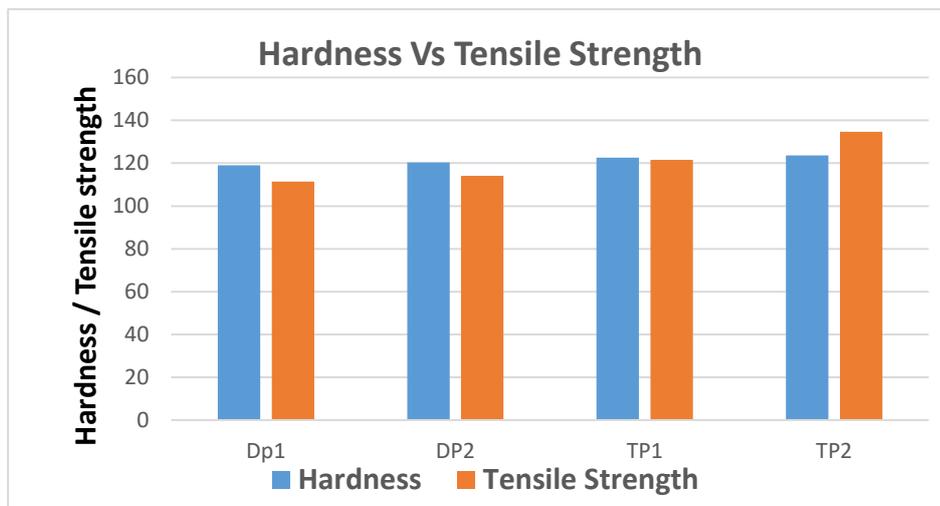


Fig 5.9 Tensile strength variation with Hardness

VI. CONCLUSION:

Aluminum based metal matrix composites have been successfully fabricated by melt stir method by three step addition of reinforcement combined with preheating of particulates. The porosity can be reduced by constant stirring, maintaining the optimum melt temperature. Uniform distribution of the particulate and isotropic property of the composite can be obtained by melt temperature of 750°C and stirring by the alumina stirrer until pouring the melt.

The particles are distributed more uniformly in dual particle composite than the triple particle composite. Al-7075/Al₂O₃ composites have shown higher hardness when compared to the hardness of casted Al-7075 alloy. The wear increased with increase in load. Also the wear in triple particle is found to be greater than the dual particle. mass loss found to increase with increase in speed. Also the mass loss in triple particle is found to be greater than the dual particle.

The co-efficient of friction found to increase with increase in load. Also the co-efficient of friction in triple particle is found to be greater than the dual particle. The co-efficient of friction found to increase with increase in speed. Also the co-efficient of friction in triple particle is found to be greater than the dual particle. Delamination and broken particles are observed with higher speed and higher load in the wear track analysis.

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