Effects of alumina (al2o3) addition on the mechanical properties and structure of nickel aluminide composites

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Abstract - **In this research work, Ni-Al alloy (Ni-25wt%Al) was designed and produced, composites were developed from the alloy using alumina as reinforcement material at varying weight percentage ranging from 5wt% to 30wt% using stir casting process for the production. Microstructures of the specimens were investigated using metallurgical microscope. Effects of weight percent alumina on the mechanical and physical properties (hardness, toughness, ultimate tensile strength, percentage reduction and density) nickel-aluminides were studied under ASTM standards. Tensile, hardness, impact and compressive tests were performed to understand the change in mechanical properties with respect to corresponding changes in composition. The results showed that ultimate tensile strength increased as the alumina content increased from 0wt% (619 MPa) to 10wt% (630 MPa), the hardness value of the composite decreased with increase in alumina content. The absorbed energy and percentage reduction of the composites decrease with increasing alumina. Comparatively, Ni-25wt%Al + 10wt% alumina gives better properties within the experimental conditions**

keywords - **Alumina, Mechanical Properties, Structure of Nickel, Aluminide Composites**

I. INTRODUCTION

Composite can be defined as those materials composed of two or more components with different properties and boundaries between the components as noted by Therabornkul and Sukasen (2005). A large number of materials are included under this definition, some of them naturally occurring such as wood, made of cellulose fibers in the lignin matrix or the human bone, made of fiber-like osteons embedded in an interstitial bone matrix, all existing materials that can be defined as composite, this work is focused on the study of the particulate reinforced composite (PRC) usually referred to as advanced composites. These composites can be defined as a man-made blend of two or more components one of which is made up of stiff, particulates and the other a binder of matrix which holds the particulates in place. The use of man-made particulate reinforced composites (PRC) dates back to ancient times, as when addition of stones to reinforce clay bricks was invented. The interaction between fibers and matrix during fracture provides the high fracture toughness of CMC. This interaction is carefully designed using the complementary concepts (CES selector, (2009) and Hall and Clyne, (1996). Thus, the abrasive wear of 2024 aluminium under a 1 kilogram load was shown to be 6 times greater than the wear of the same alloy containing 20% volume fraction of silicon carbide whiskers Reddy and. Zitoun (2011), An alumina – silica fibre – reinforced aluminium piston used in Toyota automobiles demonstrated an 85% improvement in wear resistance over the cast iron piston with nickel insert. Stronger and better materials are always in use and will always be in demand; composite materials offer the only leading hope of achieving certain space-age requirement. Not only are unusual properties expected from such composite products may be made economically by mass production techniques. Designs of composites that utilize unique or unusual mechanical and physical properties appear desirable.

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II. MATERIALS AND METHODS

Materials

The materials involved is this study include:

1. Nickel powder of 99.8% purity and average size of 3µm(Inco Speciality Powder Product, Swansea, UK)
2. Alumina powder; CT3000SG α-alumina (Alcoa Industrial Chemical, Europe) of purity 99.8% and particle size of range 4-6µm.
3. Commercial pure Aluminium
4. Crucible furnace
5. Motorized stirrer
6. Sand mould
7. Weighing balance
8. Emery papers
9. Etchant
10. Petrish dishes
11. Muffle furnace
12. Pattern

Methods

The following methodologies were put in place to achieve the results

The pattern was placed on a bottom plate and a drag box was located around it. After taking care about the position of the runner and ingate, the thickness of the sand around the casting was carefully chosen. The mould was filled with the facing sand. The sand was carefully rammed. The rest of the volume of the drag box was then filled with backing sand and rammed. The drag was inverted and the cope (half of the two piece pattern) was assembled to the drag half.

Cope box was made to sit on the drag box using alignment and closing pins. Parting Powder was sprinkled on the exposed surface of the drag box. Runner and riser were placed at appropriate positions facing sand,then backing sand was again filled in the cope box and rammed to set, vent holes were provided for passage of gases. The drag and cope were seperated, pattern was removed with utmost care being taken so as not to cause any damage to the mould cavity. Drag and cope halves were joined and locked with the help of closing pins. The mould was left for two days to dry.

In addition Various weight percents of nickel and specified aluminium were weighed out, master alloys of Ni-25wt%Al, Ni-40wt%Al, Ni-45wt%Al, Ni-50wt%Al and Ni-55wt%Al were prepared. The nickel for each master alloy was heated to temperature of 1600°C and the relevant or specified weight percent of aluminium was added to corresponding Ni percentages to produce respective Nickel-aluminides, taken account of the melting loss in aluminium for each master alloy. The resultant molten Nickel-aluminide was allowed to super heat for about 20minutes.The casting temperature was 1300°C. The prepared melt were poured into the prepared mould and allowed to solidify. Five samples were produced from each Nickel-aluminide master alloy for experimental tests. Besides, these calculation were undertaken to achieve final results: charge calculation composite charge calculations. In overall, mechanical tensile tests, compressive test, impact test hardness test, micro- structural examination were investigated.

III RESULTS AND DISCUSSION

Impact Test

The toughness of ductile-matrix/brittle-particle composites Table 1, suggested that the ceramic inclusions hardened the metal/inter-metallic by the mechanism of crack bridging. Toughness is derived from energy dissipation in the ligaments due to plastic deformation as the ligaments stretch to failure between the crack surfaces.

Table 1: Toughness (Energy absorbed) by of Ni-25wt%Al and its composites.

S/N	SAMPLE	TOUGHNESS (JOULES)
1	Ni-25wt%Al	46.00
2	Ni-25wt%Al + 5wt% Al_2O_3	41.00
3	Ni-25wt%Al + 10wt% Al_2O_3	36.00
4	Ni-25wt%Al + 15wt% Al_2O_3	32.00
5	Ni-25wt%Al + 20wt% Al_2O_3	28.00

6	Ni-25wt%Al + 25wt% Al_2O_3	23.00
7	Ni-25wt%Al + 30wt% Al_2O_3	18.5.00

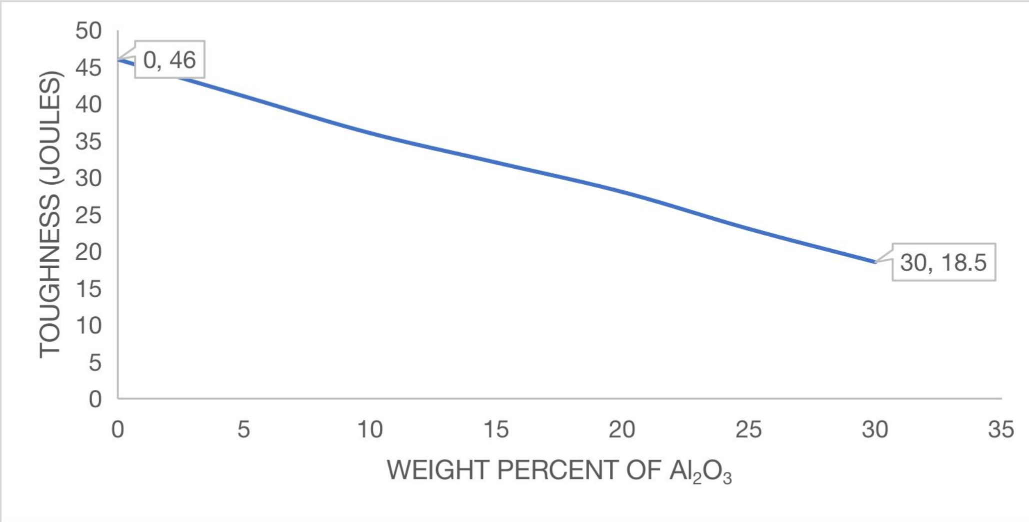

Fig. 1: Toughness strength of Ni-25wt%Al /Al_2O_3 composites with respect to weight percent of Al_2O_3.

The energy absorbed by Ni-25wt%Al composites decreased as the weight percent of Al_2O_3 increased from 46.00 Joules for 0wt% Al_2O_3 to 18.50 Joules for 30wt% Al_2O_3, the decrease is due to a decrease in the energy dissipation in the ligaments due to poor plastic deformation as the ligaments stretch to failure between the crack surfaces, Calow and Moore 1972.

Results of Young's Moduli

Increasing the weight percent of Al_2O_3 content enhances the ultimate tensile strength of the Ni-25wt%Al composites relatively from 619.00MPa for Ni-25wt%Al to 645.00MPa for Ni-25wt%Al+10wt% Al_2O_3, this agrees with the inverse rule of mixture (Reuss-Model) thereafter decreases through 15-30wt% Al_2O_3 at 617MPa to 461MPa respectively(Table 2 and Fig.2), this also agrees with the rule of mixture which also states that, there will be a range of particulate fraction in which the composite is weakened by further addition of particulate. These increases in the strengths of the inter-metallic composites is probably due to the increase in dislocation density, as a result of crack bridging mechanism, partially debonding of the interface between the ductile phase (matrix phase) and brittle phase (reinforcement) leads to an extensive plastic deformation of the ductile phase and therefore is favourable for the strengthening of the composite according to Pyzik et al. 1986. This can also be attributed to the diffusion bonding of solid state nickel to alumina, that $NiAl_2O_4$ spinal formation can result in a stronger interfacial bond, and therefore small amount of nickel oxide (exsiting on the nickel surface) are beneficial for this reaction as suggested by Calow et al. 1971, Calow and Moore 1972. Analytically, the results show that Ni-25wt%Al + 10wt%Al_20_3 comparatively gives highest valves of ultimate tensile strength when compared with other composites under scope of this research work. Also, Ni-25wt%Al + 30wt%Al_20_3 gave the least ultimate tensile strength value of 461MPa.

Table 2: Ultimate Tensile stresses of Ni-25wt%Al and its composites

S/N	SAMPLE	ULTIMATE TENSILE STRENGTH (MPa)
1	Ni-25wt%Al	619.00
2	Ni-25wt%Al + 5wt% Al_2O_3	630.00
3	Ni-25wt%Al + 10wt% Al_2O_3	646.00
4	Ni-25wt%Al + 15wt% Al_2O_3	617.00
5	Ni-25wt%Al + 20wt% Al_2O_3	615.00
6	Ni-25wt%Al + 25wt% Al_2O_3	580.00
7	Ni-25wt%Al + 30wt% Al_2O_3	461.00

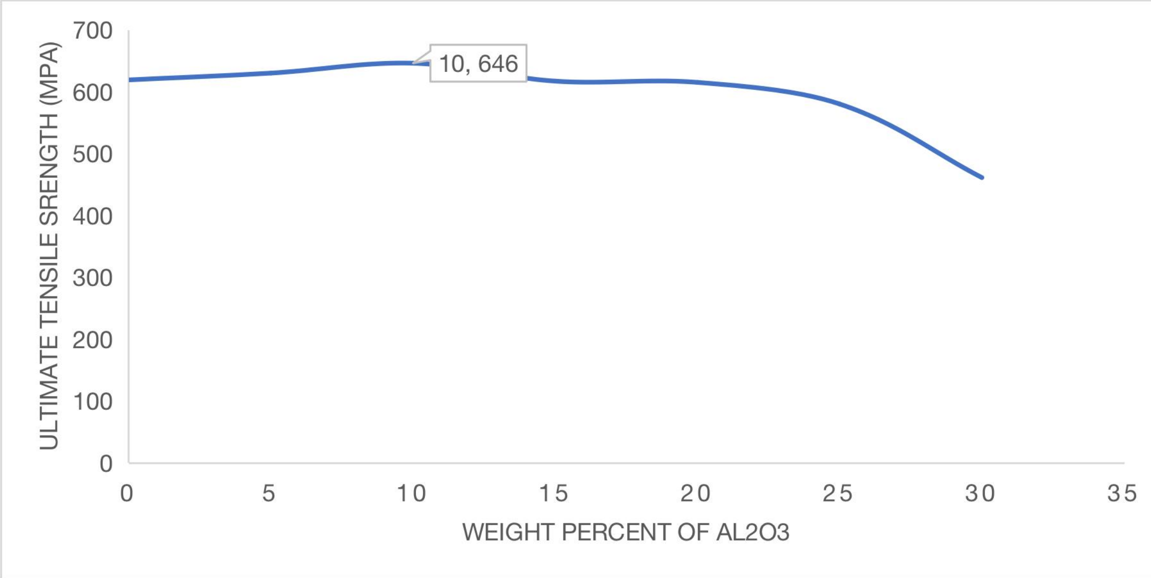

Fig. 2: Ultimate Tensile strength of Ni-25wt%Al /Al_2O_3 composite with respect to weight percent of Al_2O_3.

Micro Structural Analysis

Figs. 3. 4. 5, 6, 7 and 8, show microstructures of specimens with different aluminum and alumina additions. All the structures of the nickel-aluminides show emergent of flake-like structure, their grain boundaries are difficult to be distinguished which may probably because the structures consist largely of eutectic grains.

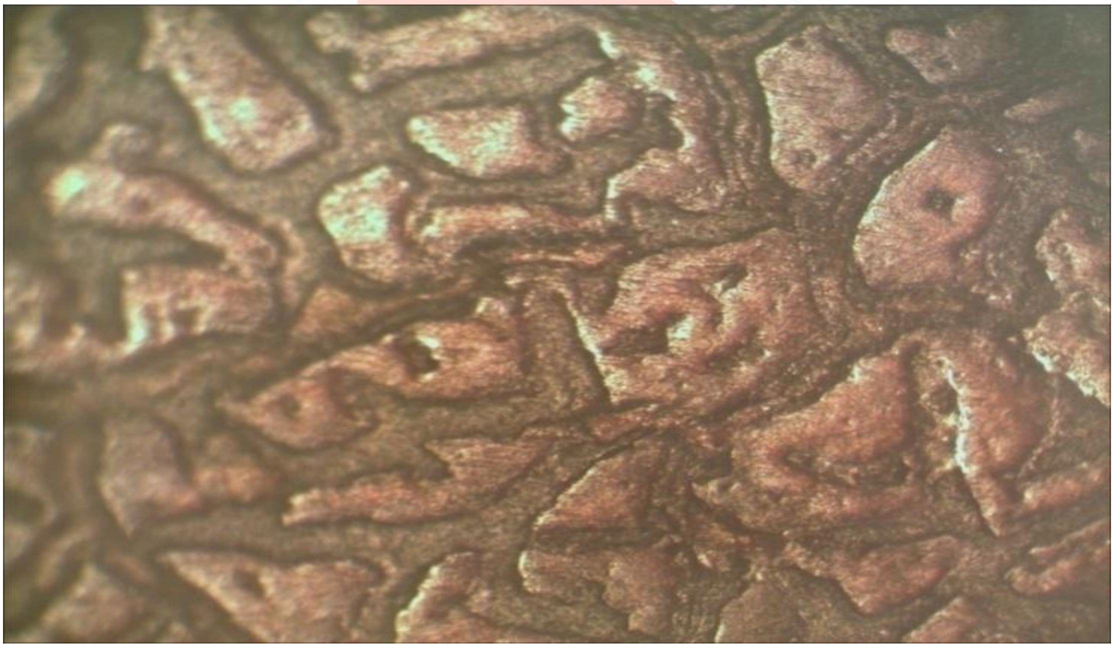

Fig. 3: Microstructure of Ni-25wt%Al X100

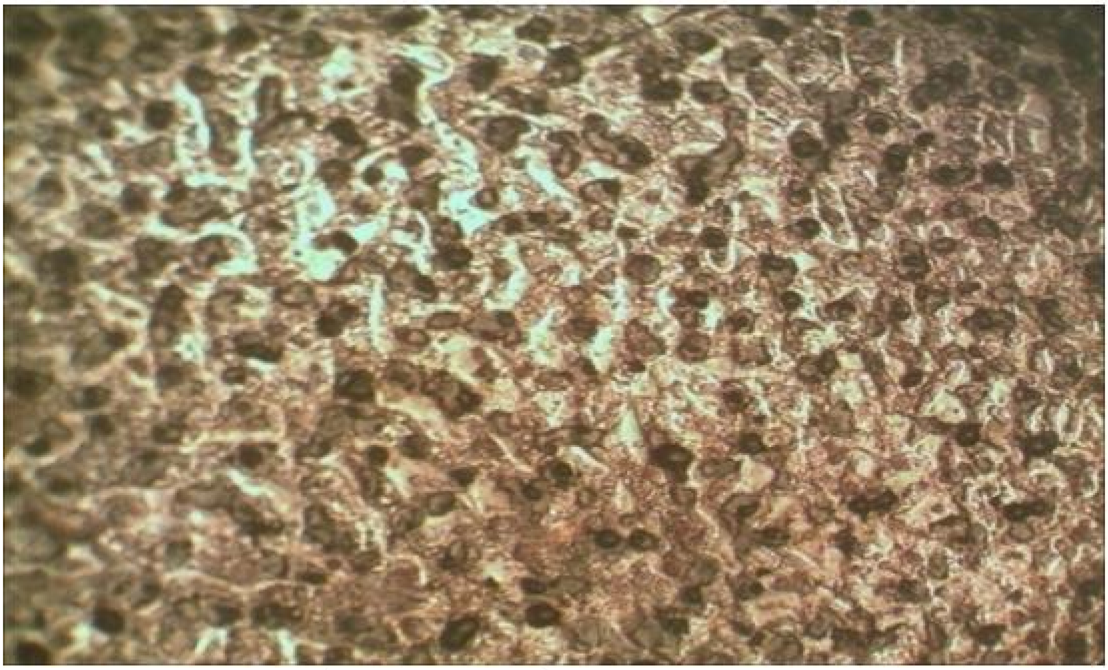

Fig. 5: Microstructure of Ni-25wt%Al + 10wt% Al_2O_3 X100

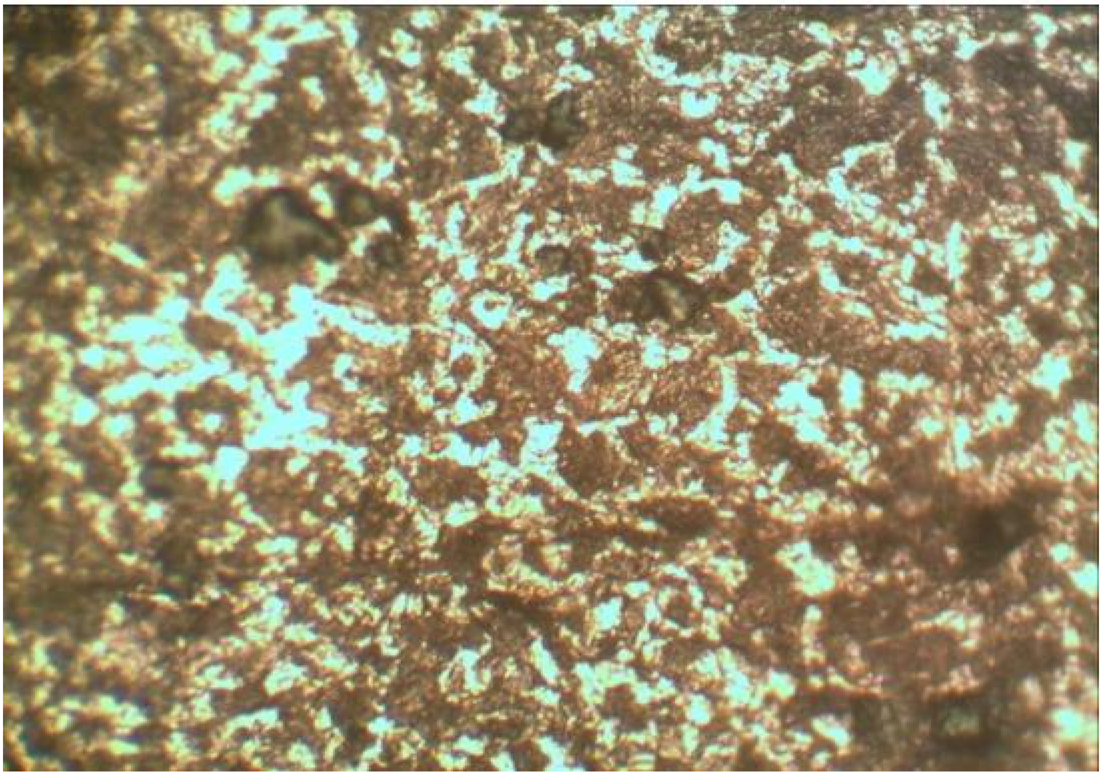

Fig. 6.: Microstructure of Ni-25wt%Al + 15wt% Al_2O_3 X100

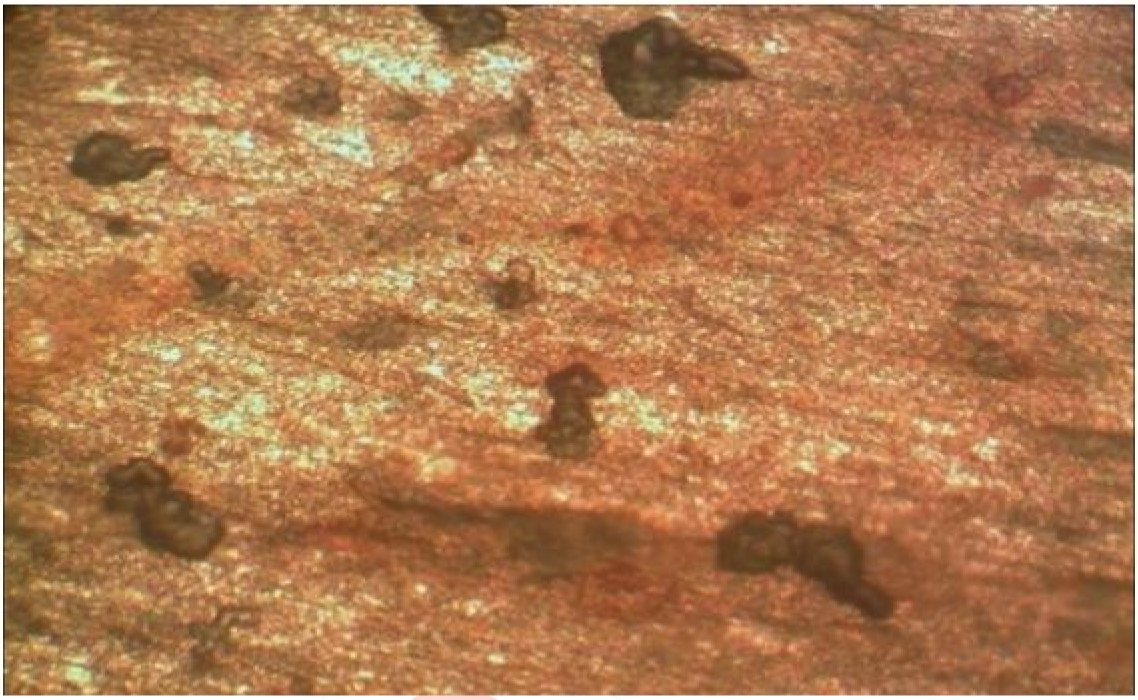

Fig 7 Microstructure of NA3 + 25wt% Al_2O_3 X100

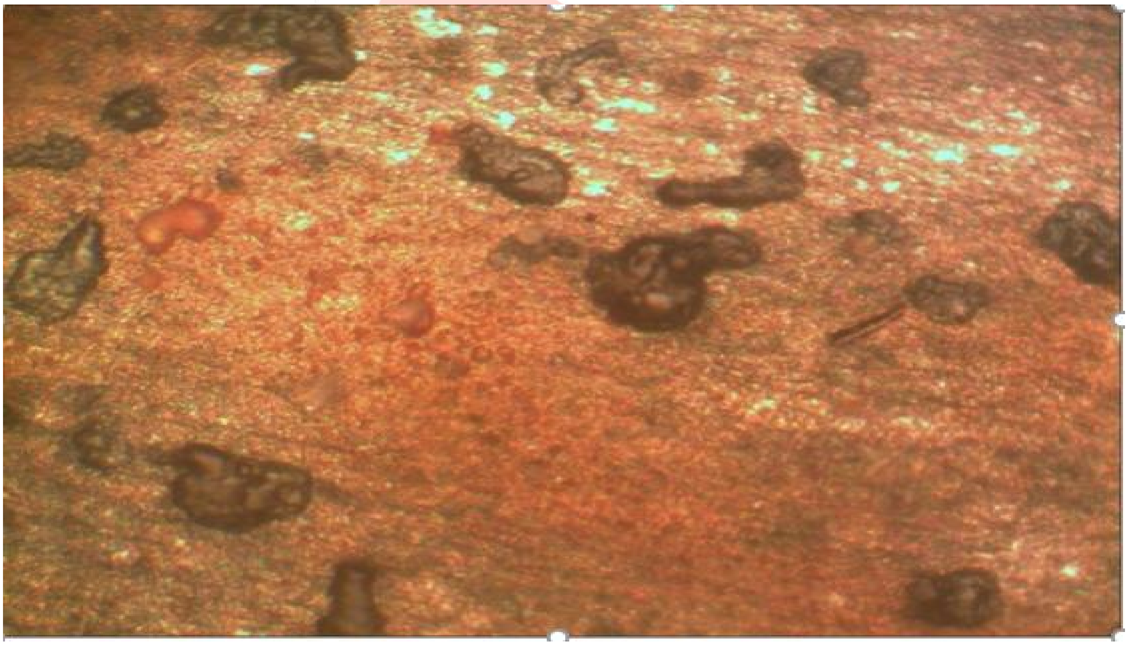

Fig. 4.7: Microstructure of Ni-25wt%Al + 30wt% Al_2O_3

The microstructures are quite different, the composite Ni-50wt%Al containing 25wt% Al_2O_3 comparatively shows homogeneous distribution which can be associated with its better properties as shown in Figs. 3 and 4 with 35.25wt% of alumina of all composites of both nickel and nickel-aluminides show comparatively better distribution of alumina when compared with other composites of Figs. 5 and 6. Further addition of alumina above 25wt% results to agglomeration of the alumina as shown in Figs. 7 and 8.

IV. Conclusion

Within the scope of this research work, the following conclusions were made:

Hardness of Nickel-aluminides (Ni-25wt%Al) composites increases with increasing alumina content. Increasing alumina content in nickel-aluminide increases its ultimate tensile strength up to 10wt% of alumina thereafter decreased when it was increased from further. That toughness of nickel-aluminides – alumina composites decreases with increase in weight percent of alumina.. Percentage reduction of nickel-aluminides-alumina composite decreases with increase in weight percent alumina. Comparatively, Ni-25wt%Al + 10wt% alumina has better properties for aerospace application. In overall, Nickel-25wt%Al + 10wt%Al_2O_3 has the desire properties for the production of rocket nozzles and turbine blades in aerospace industries.It also has desire properties for production of automobile block engines.

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