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Effect of Nickel and Chromium Addition on the Microstructure and Mechanical Properties of Aluminium – 4% Zinc Alloy

W.C Okafor[1], J.U. Odo[2] and E. E. Nnuka[2]

[1]Department of Mechanical Engineering, Chukwuemeka Odumegwu Ojukwu University Uli, Nigeria
[2]Department of Metallurgical and Materials Engineering, Nnamdi Azikiwe University, Awka, Nigeria.

ABSTRACT

This work studied the effect of microalloying on the microstructure and mechanical properties of Al. 4%Zn alloy. The mechanical properties studied were yield and ultimate tensile strength, % elongation, compressive strength and hardness. The tests were conducted using the ASTM E8, E10 and E20 standards. Microstructural analysis was done using metallurgical microscope model Olympus PMA–3 and the micrographs were obtained with an attached camera. The results obtained showed that nickel and chromium modified the structure of the studied alloy and therefore improved the mechanical properties.

Keywords: Nickel, Chromium, Microstructure, aluminium, ASTM, SFE, UTS, CBR, PMA

I. INTRODUCTION

The demand for aluminium alloys for industrial applications is on the increase. The major areas of demand are the automobile, aerospace, aviation, ship building and allied industries where the high strength-to-weight ratio of aluminium alloys is of great advantage. Aluminium and its alloys are also of increasing demand because of their good formability, excellent corrosion resistance and fatigue response, high conductivity and moderate strength. They are therefore used for engine blocks, wheel frames, bicycle frames and machinery components (Wang et al, 2004). They are also used for foils and conductor cables because of their light weight, durability and ductility (Nnuka, 2000).

The binary Al-4%Zn alloy has low strength but is of high ductility. Therefore, for its application in demanding environments, additional strengthening is necessary, hence micro-alloying can be employed. The alloying elements in micro-quantities promote the formation of insoluble particles, which act as resistance to dislocation movement (Nnuka, 1985). Rudminski et al (1985) showed that the properties of aluminium alloys can be improved when modified. The position was supported by Nnuka (1985) and Gayle and Vadersande (1986). Thus it was established that the mechanical properties of Al-Zn alloys can be improved by modification of the structure with metallic elements. Nnuka and Ette (1990) delved further and established the relationship between the composition and properties of Al-Cu and Al-Zn alloy systems. This was achieved by analysis of the effects of small quantities of additives (inoculants) on the texture and microstructure of alloys. The results showed that inoculants conferred significant changes on the structure and properties of the investigated alloys with resultant improvement in strength and depreciation of plasticity. It was concluded that there was lack of simple co-relation between the observed changes in both physical and mechanical properties

Nnuka (2002) studied the atomic substructure and mechanical properties of aluminium alloys with zinc and copper. The results of the research showed that point defects impeded the motion of dislocation and so strengthened the alloys substantially with a corresponding decrease in relative elongation. The dopants (V, Nb, Sb and Ta) were added in percentages of 0.15, 0.5 and 1.0. It was observed that only Sb increased both the UTS and relative elongation and by 100%. It was then postulated that V, Nb and Ta which belong to the same period of the periodic table and thus with the same number of electrons in the outer shell, strengthened the alloys in a similar manner different from antimony. Stacking fault energy (SFE) was also studied and related to mechanical properties of the alloys. Nnuka (2004) further studied the effects of dopants on cast alimunium and some of its alloys. The mechanism and effects of alloying on the structure and the properties of aluminium and its alloys with copper and zinc were also investigated. The results showed that increasing the concentration of the dopants in the alloys studied (Al – 4% Zn and Al-4% Cu) was accompanied with increase in the strength characteristics (hardness and UTS) and physical characteristics (specific electron resistivity, r) but decrease in ductile characteristic (%E) as well as in thermoelectromotive force (b). This was attributed to the possible formation of substitutional solid solution between the aluminium lattice and the dopant atoms which in effect prompted reduced lattice distances and therefore translated to reduction in mean free path. Increased concentration of dopants also introduced more scattering centres in the lattice, thus boasting the mechanical properties. It was then deduced from the results that the effect of dopants on the mechanical properties depends on the concentration of alloying elements and the physics of the dopants. It was concluded that mechanical properties co-related to physical properties just as hardness (HB) and UTS co-related to r and %E correlated to b.

II. METHODS AND MATERIAL

The materials used in this work were high purity aluminium and zinc, chemically processed nickel and chromium metals used as the modifiers/alloying elements. Aluminium – 4% Zinc alloy was produced by charging known quantity of aluminium and zinc (9.8kg Al and 4.1Kg Zn respectively) using weight percent method into a heat-treatment furnace using a graphite crucible. The crucible and its contents were heated in the furnace until the alloy melted. At a temperature of 750oC, the crucible was removed from the furnace, the molten metal was properly stirred, deslagged and poured into pre-heated permanent metal moulds. On solidification, the casting was cut into the desired number of samples for re-melting and modification.

The samples for modification were charged into the furnace and heated to temperature of 750oC. The molten alloys were removed from the furnace and the modifying elements added in 0.1, 0.3, 0.5, 0.7 and 0.9 percent respectively by weight. The molten alloys with the modifying elements were mechanically stirred and returned to the furnace for 5 minutes at a holding temperature of 700oC for homogenization and uniform distribution of the alloying elements. At the attainment of the required heating time, the molten alloys were removed and cast into preheated metallic moulds. On solidification, the cast specimens were removed from the mould and then machined to the desired dimensions/ specifications for tensile tests, hardness tests, compression tests and microstructure examination according to American Society for Testing and Materials (ASTM) standard specifications using lathe machine.

The specimens for tensile, compression and hardness tests were tested using computer aided Electro-Hydraulic servo Universal Tensile Testing Machine, California Bearing Ratio Testing Machine (CBR – Model 37H50) and Rockwell Hardness Tester respectively. The specimens for microstructural examination were ground using different grades of emery paper (340, 400, 600, 800, 1000 grits), polished using gamma alumina (aluminium oxide, Al2O3) and etched in Keller's reagent. Metallurgical microscope (Model Olympus PMA-3) was used to study the microstructure and the micrographs were taken and produced with the help of a camera attached to the microscope.

III. RESULTS AND DISCUSSION

The results of the mechanical property tests – yield stress, ultimate tensile stress, percentage elongation, compressive stress and hardness are presented in Table 1 and Figures 1 – 5.

Table 1 Mechanical Tests Results

Specimen No.	Specimen Composition	Yield Strength (N/mm^2)	Ultimate Tensile Strength (N/mm^2)	Elongation (%)	Compressive Strength (N/mm^2)	Hardness (HB)
1	Control (A)	80	109	3.0	38.8	25.4
2	A + 0.1%Cr	80.8	110	2.9	39.2	25.8
3	A + 0.3%Cr	81.5	111.65	2.85	40.0	26.0
4	A + 0.5%Cr	82.3	112.5	2.72	41.5	26.7
5	A + 0.7%Cr	84.0	113.0	2.60	43.0	27.0
6	A + 0.9%Cr	86.5	115.5	2.50	45.0	27.2
7	A + 0.1%Ni	81.7	111.5	2.80	41.0	25.5
8	A + 0.3%Ni	83.0	112.5	2.65	43.5	27.0
9	A + 0.5%Ni	84.5	114.0	2.50	45.0	28.5
10	A + 0.7%Ni	86.0	115.5	2.45	46.2	30.0
11	A + 0.9%Ni	87.5	118.0	2.30	48.0	32.5

Note: Control (A) = 96%Al – 4%Zn

The results of the mechanical properties tests as shown in Table 1, indicate that the addition of nickel and chromium to aluminium – 4%zinc alloys have pronounce effects on the properties studied. The yield stress, ultimate tensile strength, compressive strength and hardness of the resultant alloys increased with increase in the percentage of the alloying elements. Addition of zinc to aluminium forms an α – primary of solid solution. The addition of the two alloying elements – nickel and chromium to aluminum-zinc alloy forms finely insoluble hard particles of second phase in the soft matrix (Polmear, 2009). This is because the two-elements have higher melting points and do not dissolve in the molten alloy. Instead they form insoluble hard particles in the matrix of the alloy which impede dislocation motion and the alloy is dispersion strengthened. The particles of the alloying elements, form barriers to dislocation movement and produce strain hardening effect which increased tensile strength, hardness and compressive strength but reduced percentage elongation or ductility (Soo and Duck, 2000).

As could be seen from Table 1 and Figures 1 – 5 (Appendix 1) nickel has higher strengthening effect on the resultant alloys than chromium. This could be attributed to better uniform dispersing of nickel particles in the alloys than chromium particles probably because of smaller atomic radius (0.125mm) as compared to that of chromium (0.128mm). The smaller atomic radius may have induced the particles of nickel to have more concentration with higher surface interaction with the atoms of the matrix of the base alloy. This created more solidification sites resulting in more grain boundaries and inter-atomic distance displacements and greater barriers to dislocation movement. From Table 1 and Figure 5, the lower hardness value of nickel when compared to that of chromium at 0.1% composition may be due non-even dispersion of nickel particles resulting from non-uniform or inadequate stirring of the molten alloy with the dispersed particles before casting. Also this could be attributed to presence of impurities which may have affected uniform solidification resulting in the segregation of the grains at the grain boundaries.

Investigation of the relationship between microstructure and mechanical properties indicate that change in the structure affected the mechanical properties. It was observed from Table 1, Figures 1-5 and Plates 1-11 (Appendix I & II) that the addition of nickel and chromium improved the microstructure of Al – 4% Zn alloy. The needle-like and primary dendrites of solid solution of zinc in aluminium matrix were modified to spherical shaped inter-metallic compounds. This is suspected to had reduced the early cracking/failure of the alloy caused by the needle-like dendritic structure. The increase in the percentage of nickel and chromium in the alloys, created more nucleation/solidification sites, reduced the size/length of the atomic lattice distance and increased barriers to dislocation motion hence improving mechanical properties. The increase in the yield strength, ultimate tensile strength, compressive strength and hardness of the resultant alloys are attributed to improved grain structure and reduced lattice distances which impeded dislocation movement resulting in strain hardening of the produced alloys.

IV. CONCLUSION

- The yield stress, ultimate tensile strength, compressive strength and hardness of aluminium - 4% zinc alloys increased with increase in percentage of the alloying elements.
- The ductility or percentage elongation of aluminium-4% zinc alloys decreased with increase in the percentage of nickel and chromium elements addition.
- The increase in strength and hardness of the alloys studied was higher for those alloys having nickel than those with chromium.
- The microstructure of aluminium-4% zinc alloys was modified with addition of nickel and chromium which resulted to improved mechanical properties.
- The higher hardness of the alloy with 0.1%Cr than that of 0.1%Ni may be due to the presence of impurities or lattice atomic segregation resulting from non uniform solidification or lattice atomic stress or strain.
- Mechanical properties of aluminium alloys depend not only on the concentration of alloying elements, but also their relative chemistries with each other.
- The resultant alloys are recommended for aerospace applications and engine pistons production because of their improved strength and higher wear resistance.

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Appendix I

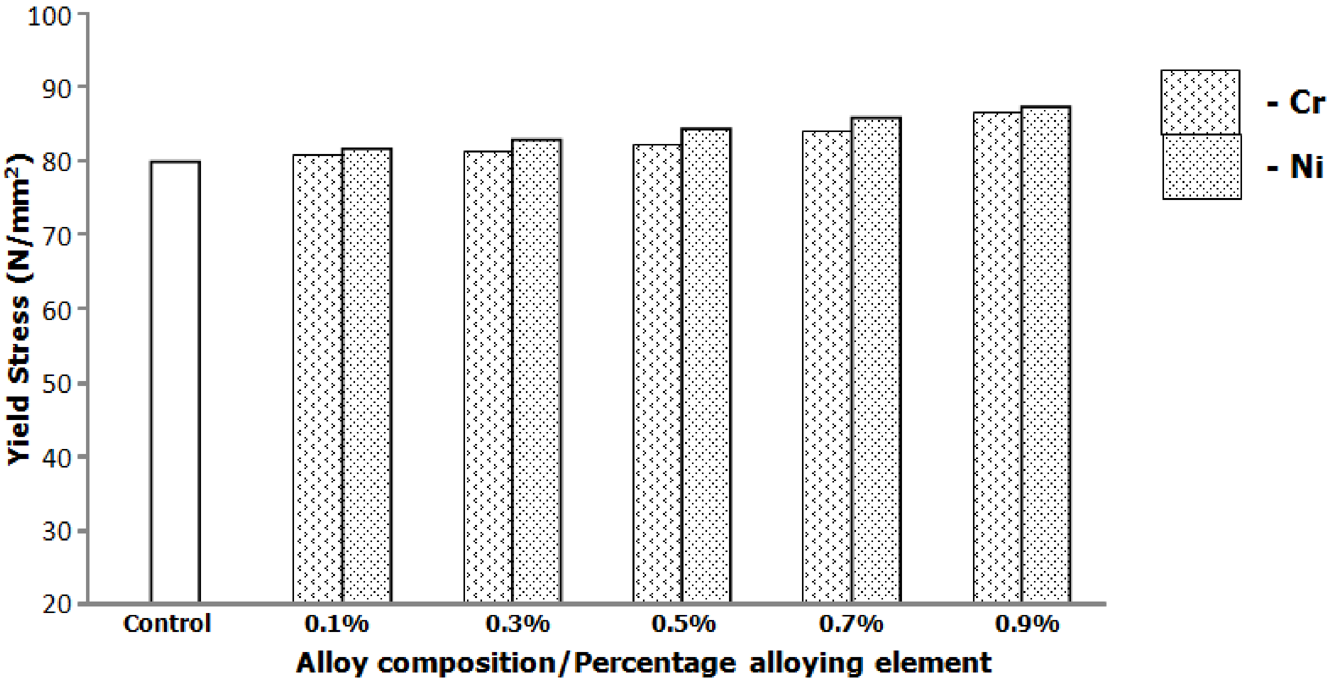

Figure 1: Relationship between percentage of the alloying elements and yield strength of aluminium – 4%zinc alloys.

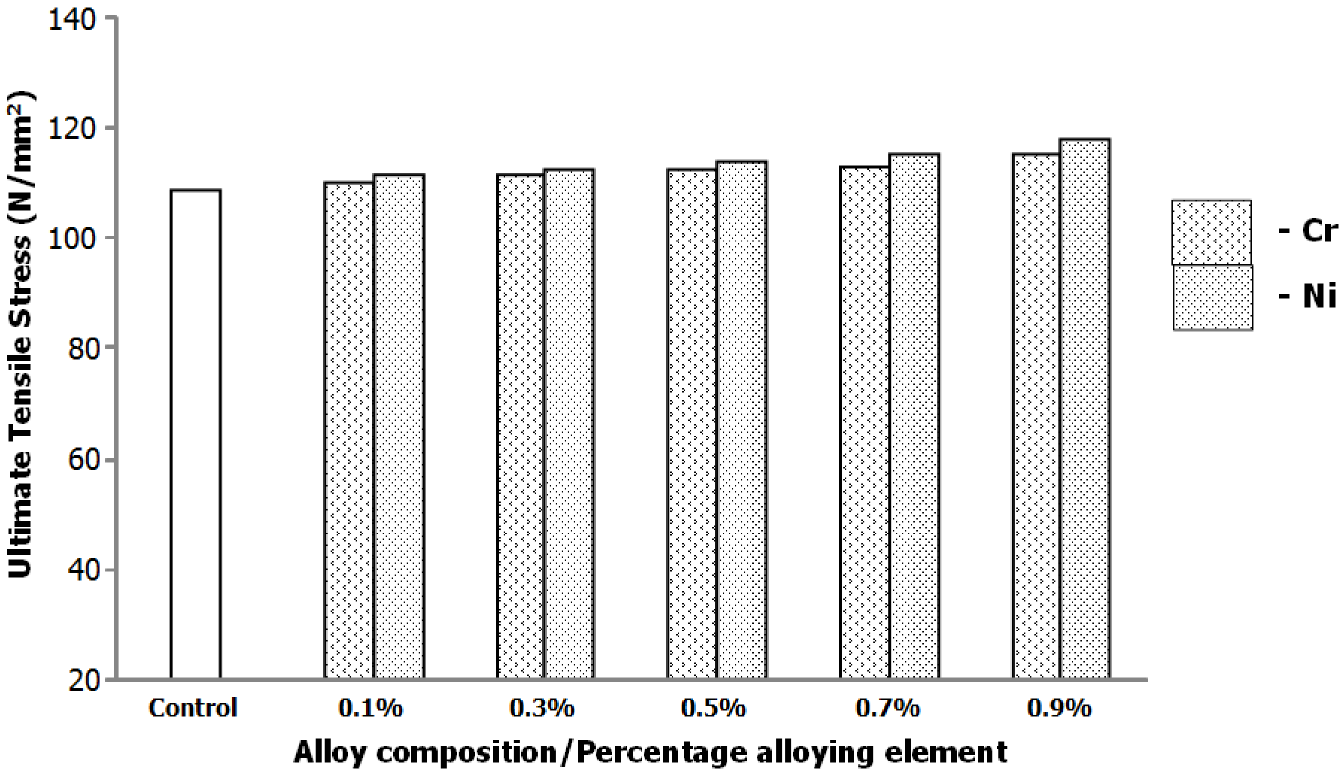

Figure 2: Relationship between percentage of the alloying elements and ultimate tensile strength of aluminium – 4%zinc alloys.

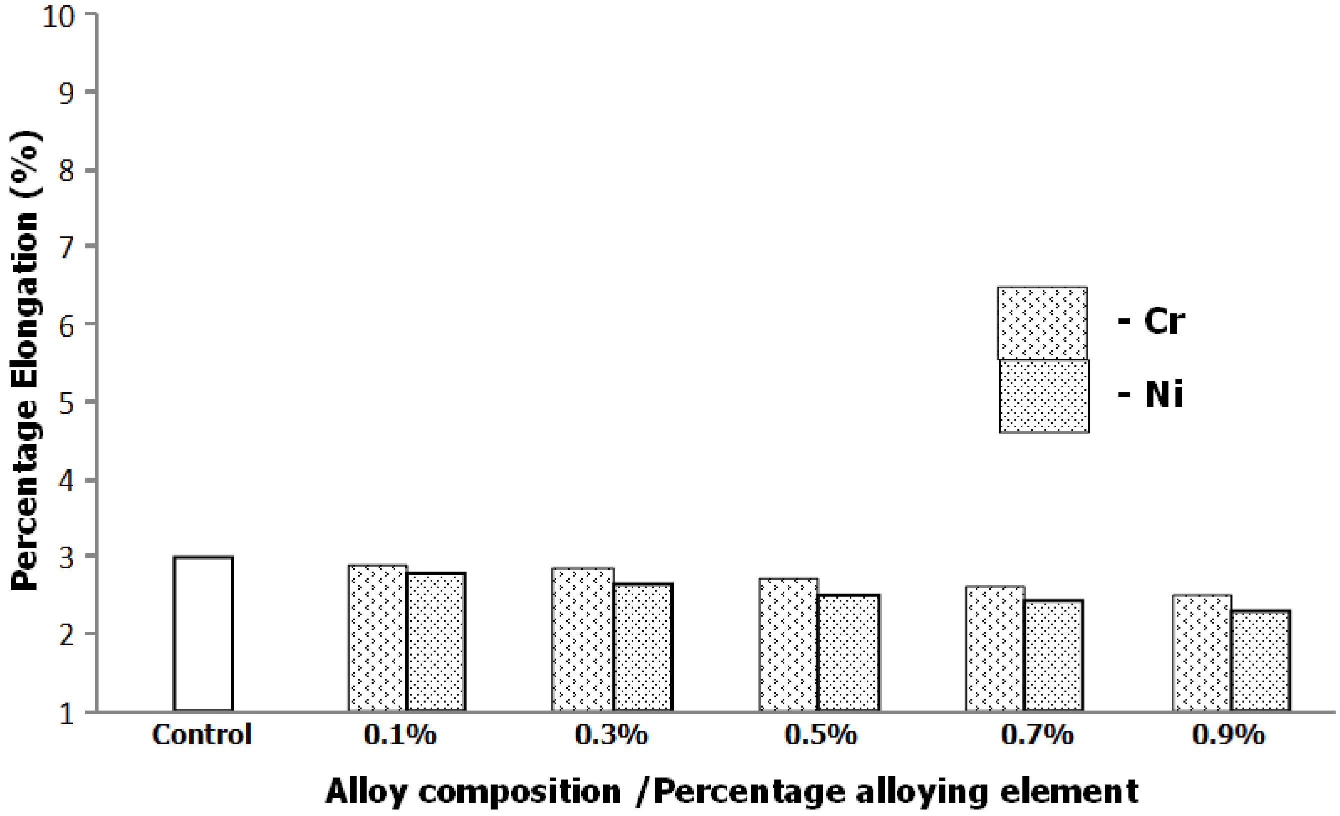

Figure 3: Relationship between percentage of the alloying elements and ductility (Percentage Elongation) of aluminium – 4%zinc alloys.

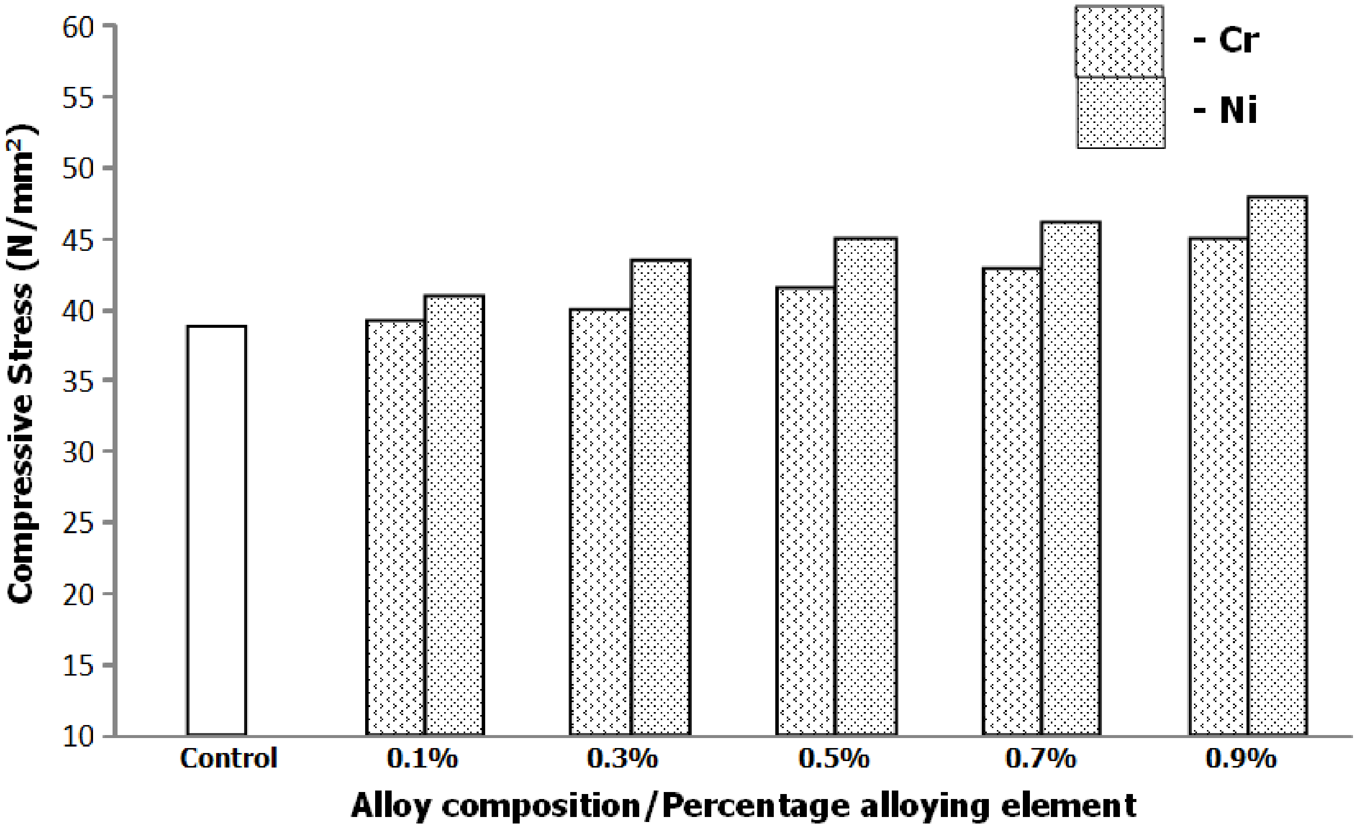

Figure 4: Relationship between percentage of the alloying elements and compressive strength of aluminium – 4%zinc alloys.

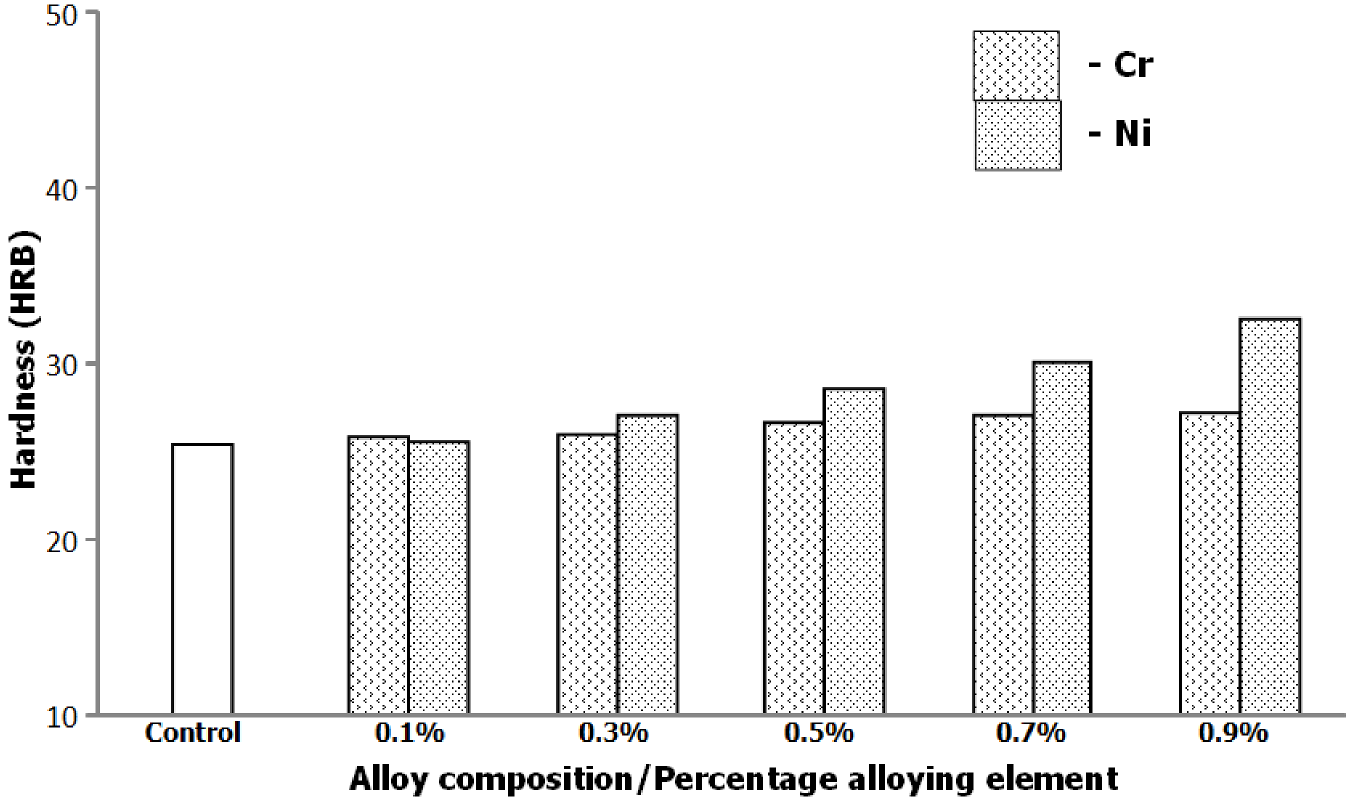

Figure 5: Relationship between percentage of the alloying elements and hardness of aluminium – 4%zinc alloys

Appendix II

Micrographs

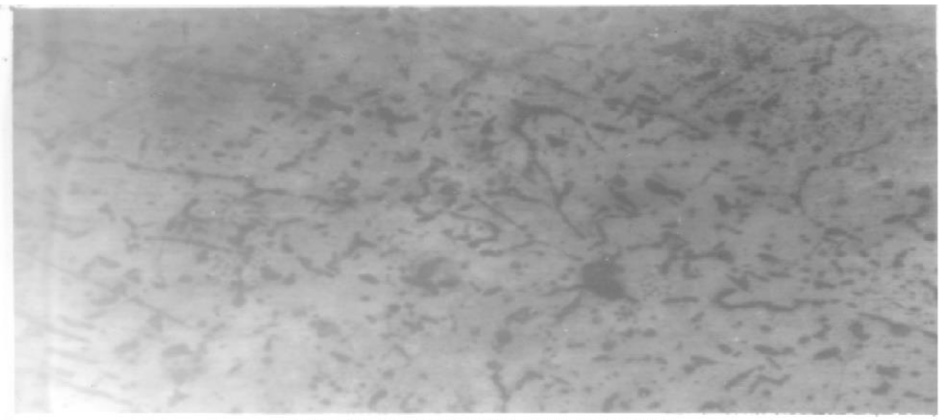

Plate 1: Control (Al-4%Zn) alloy X 200

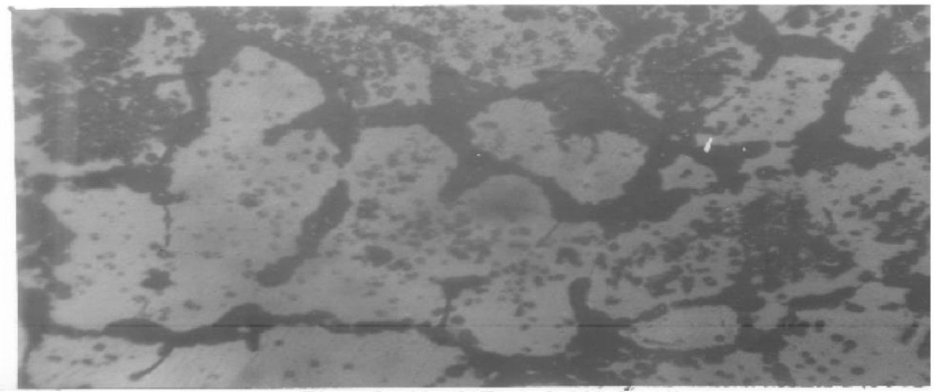

Plate 2: Al-4%Zn + 0.1% Cr alloy X 200

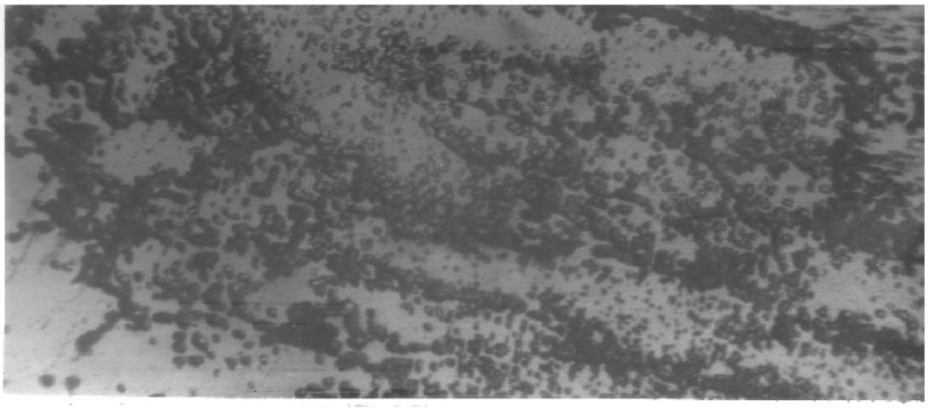

Plate 3: Al-4%Zn + 0.3% Cr alloy X 200

Plate 4: Al - 4%Zn + 0.5% Cr alloy

Plate 5: Al - 4%Zn + 0.7% Cr alloy

Plate 6: Al - 4%Zn + 0.9% Cr alloy

Plate 7: Al - 4%Zn + 0.1% Ni alloy

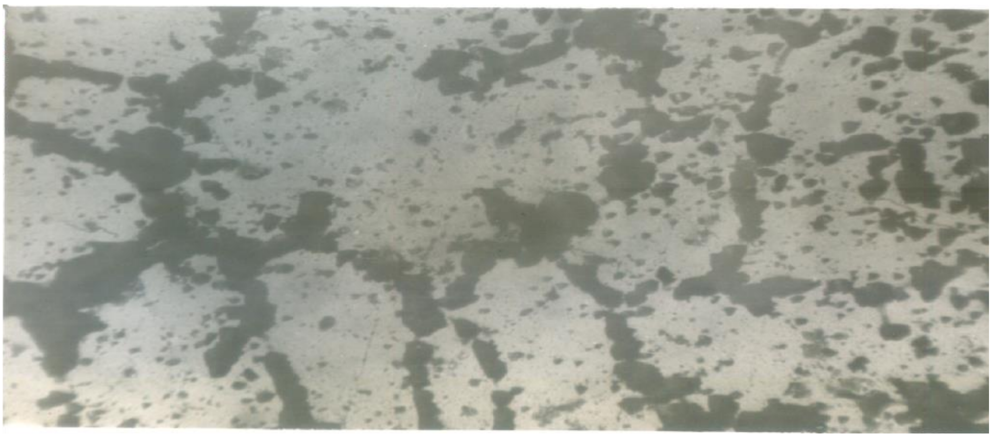

Plate 8: Al - 4%Zn + 0.3% Ni alloy

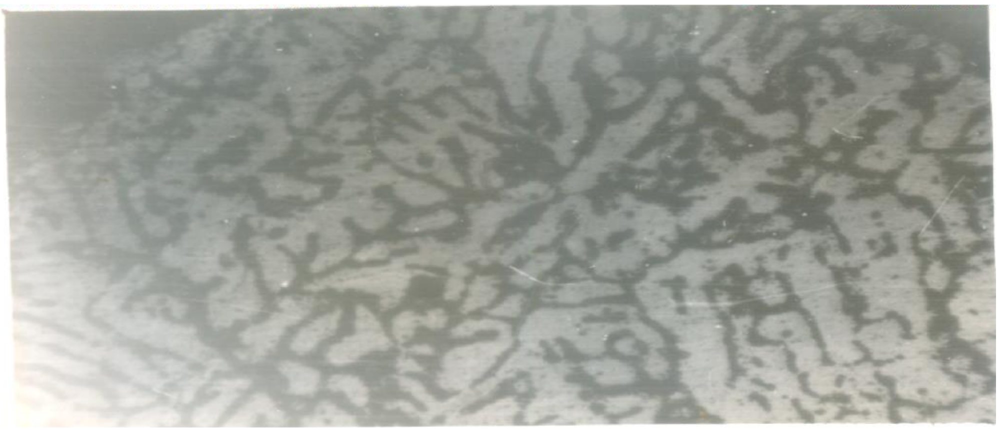

Plate 9: Al - 4%Zn + 0.5% Ni alloy

Plate 10: Al - 4%Zn + 0.7% Ni alloy

Plate 11: Al - 4%Zn + 0.9% Ni alloy