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NICKEL AS AN ALTERNATIVE AUTOMOTIVE BODY MATERIALS

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ABSTRACT

The study of thermal, chemical and mechanical properties of pure nickel being an alternative automotive body material is presented in this paper. Current automotive components are mainly used steel as a body material. Due to the increasing demand of high performance and related issues interest moving towards other materials to replace the existing steel. The hardness value of both heat treated and non-heat treated pure nickel does not change after annealing. The hardness values are in the range of 118 to 123 HV. As the annealing temperature increases, the ultimate tensile strength, yield strength and young modulus decreases, which show the ductility increase. The highest ultimate tensile strength of pure nickel at 300ºC annealed temperature is 758.78 MPa. X-ray diffraction (XRD) studies confirmed pure nickel of face centered cubic (FCC) with lattice constant measured as 0.3492 nm for unannealed sample, which is increased to 0.3512 for annealed samples. The corrosion rate of both annealed, and non-heat treated pure nickel is in the range of 0.0266 to 0.048 mm/year.

Keywords: Alternating material, nickel, annealing, corrosion resistance.

INTRODUCTION

Due to the increasing demand of high-quality exterior panels, better functional properties and lower weight in the automotive industry, researches on different materials have been conducted to alternate the existing automotive body material, Steel. One of the expectations of an alternative automotive body is weight reduction. This is due to the weight of the automotive body will affect the energy consumption of the automotive. Every 56.69 kg weight reduction results in a gain of 0.09-0.21 km per liter fuel economy. Therefore, the lightweight materials have been conducted to achieve fuel efficiency. Cui et al. (2008) stated that approximately 40% of the weights of the automotive are from automotive body and interior account. Therefore, automotive body materials change from steel to aluminium. Although, conventionally the weight of the steel is higher than aluminium, and the cost of the steel is lower than aluminium. Besides the weight of the material, the mechanical properties of the material in an automotive body are also important in order to increase their performance. Edwards (2004) stated that the materials with high specific stiffness and strength properties, the highly efficient lightweight load bearing structures to be produced. High strength and strain alloy steel sheets with transformation-induced plasticity are used for body panel. The properties of alloy steel allow deep drawing; provide resistance to denting, and opportunity to use a lighter gauge to reduce vehicle weight. The material used in an automotive body should have the properties of high fracture toughness due to the ability to absorb energy in case of high speed crashes.

Klarstrom (2001) stated that the nickel and nickel based alloys are important to modern industry due to the ability to withstand a wide variety of severe operating conditions involving corrosive environments, high temperatures and high stress. Nickel, a transition metal is ductile and tough due to it possesses a face-centered cubic crystal structure up to its melting point. It is used for making stainless steel, low alloy steels, cast iron and etc. It is widely used in variety of applications in food processing equipment, chemical shipping drums, battery manufacturing, aircraft gas turbine, caustic, handling equipment and piping. From galvanic series of metal, nickel is more to least active element which mean that the tendency of nickel to corrode is low. According to Rebak et al. (2001), nickel has good resistance to corrosion in the normal atmosphere, in natural freshwater and deaerated non-oxidizing acids, and has excellent resistance to corrosion by caustic alkalies. Lee et al. (2008) stated that the automotive body must fulfill mechanical performance requirements such as deflection, stiffness and strength, in an extensive amount of structural design considerations and components. Steel is the traditional automotive body material. The steel used in automotive body need to coat due to the corrosion of the material when expose to moisture (Davies, 2003). In this research, the thermal property of pure nickel was obtained by annealing in different temperature for pure nickel. Various tests had been conducted to obtain the mechanical, chemical, structural and other properties of pure nickel. The testing includes tensile test, microhardness test, corrosion test, structural analysis by using X-Ray Diffraction and composition and morphology study by scanning electron microscope and Energy-dispersive X-ray spectroscopy. This work presents the comparison data of the mechanical and chemical properties of pure nickel with annealed samples of 300, 500 and 700ºC.

EXPERIMENTAL PROCEDURES

The characterization of pure nickel is studied as an alternative material for automotive body. The processes involve heat treatment where annealing of pure nickel at various temperatures is carried out followed by mechanical and corrosion test. Annealed and unannealed samples were prepared to dimension according to international ASTM and ASE standards (Kuroda et al., 2005). According to the Tillack et al. (1990), the stress relieving of nickel range from 425 to 870 °C. Three different annealing conditions at 300, 500 and 700 °C were chosen based on the above literature. Corrosion rate of pure nickel for both non-heat treated, and annealed samples were determined by using Eurocell Tafel extrapolation technique with GRES-DC 105 software. The samples of pure nickel were characterized for tensile, hardness morphology study and corrosion test.

Mechanical studies on tensile and hardness properties of both non-heat treated and annealed samples of pure nickel were performed using an Instron– 5585 Universal testing machine (UTM) with test speed in the range of 0.01 ~ 500 mm/min. Micro Vickers hardness testing machine MITUTOYO HM-200 was used to test all samples. For Vickers test, both diagonals were measured and average value was used to compute the Vickers hardness (HV). The hardness number is based on the surface area of the indent itself divided by the applied force, giving hardness units of kgf/mm^2. X-Ray Diffraction was used to determine the crystal structure of the specimens and identify the changes in lattice constant of non- heat treated and annealed pure nickel. Scanning electron microscope (SEM) along with energy dispersive spectroscopy (EDX) was used to observe the materials morphology in macro and submicron ranges. In this report, Energy dispersive spectroscopy (EDX) was used to confirm the composition of pure nickel on both non- heat treated and annealed.

RESULTS AND DISCUSSION

Hardness Analysis

The hardness of non-heat treated and heat treated pure nickel had been measured using micro Vickers hardness tester. The annealed temperature of pure nickel for 300, 500 and 700°C do not have large different in terms of their hardness value. Figure 1 shows the indentation of diamond in contact with the surface of the sample. For non- heat treated pure nickel, the hardness value is 123.6 HV whereas for samples annealed at 300, 500, and 700 °C, the hardness value decreased to 120.8 HV, 118.7 HV and increased to 120.5 HV respectively and their corresponding comparison can be found in Figure 2.

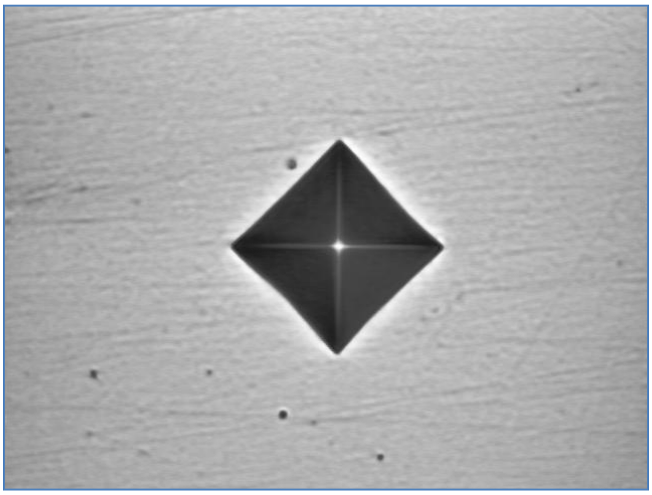

Figure 1. Indentation of diamond pyramid indenter with a 90° angle between opposite faces. Image is magnified at 50x.

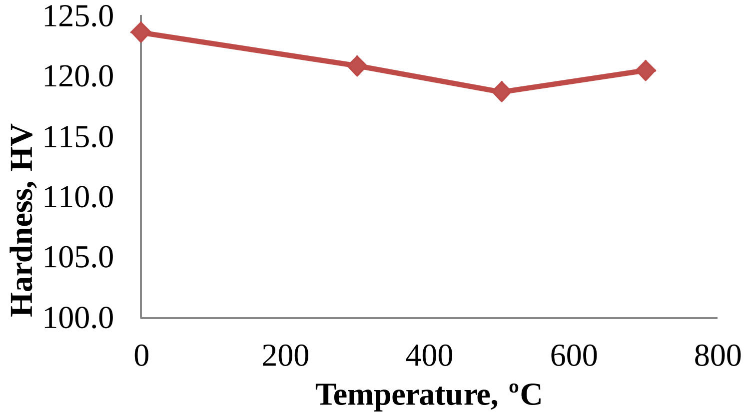

Figure 2. Hardness against annealing temperature.

The hardness of pure nickel with different annealing temperature is shown in Table 1. There is no significant change in the hardness values of pure nickel in different annealing temperature for 1 hour. The range of hardness for pure nickel at different annealing temperature is 118HV to 125 HV. According to the result obtained by Neishi et al. (2002), the hardness for equal-channel angular pressing (ECAP) of pure nickel 99.99 % purity annealing at 1 hour decreased as the annealing temperature is increased. Figure 2 shows the the hardness value of equal-channel angular pressing (ECAP) of pure nickel 99.99 %. The hardness value of pure nickel is decreasing to 100 HV as the annealing temperature increase. For annealing temperature 500 °C, the hardness value of the sample is 118 HV is in good agreement with previous study (Neishi et al., 2002).

Table 1. Hardness of pure nickel with different annealing temperature.

Pure Nickel	**Hardness values (HV)**					
	1	**2**	**3**	**4**	**5**	**Average**
Non heat-treated	120.9	127.7	139.3	111.8	118.4	123.6
300ºC- annealed	116.6	118.3	125.3	125.0	119.0	120.8
500°C- annealed	120.8	127.5	109.5	122.3	113.4	118.7
700°C- annealed	117.3	124.5	115	128.2	117.3	120.5

Tensile Analysis

Tensile test was carried out to obtain a tensile stress-strain behavior of both non -heat treated and annealed pure nickel. Table 2 shows the mechanical properties (ultimate tensile strength, Young modulus and yield strength) of the pure nickel in different annealing temperature. Ultimate tensile strength against different annealing temperature of pure nickel is presented in Figure 3. The ultimate tensile strength decreased as the annealing temperature is increased. The highest ultimate tensile strength is 758.78 MPa measured for 300 °C heat treated, and the lowest value of 368.07 MPa measured for annealed at 700 °C. The yield strength at 0.2% offsets is determined by finding the intersection of the stress-strain curve with a line parallel to the initial slope of the curve and which intercepts the abscissa at 0.2%.

Table 2. Mechanical properties of pure nickel in different annealed temperature.

Pure nickel	Ultimate tensile strength, (MPa)	Young's Modulus (GPa)	Yield Strength (MPa)	Elongation, (%)
Non heat-treated	645.47	39.37	440	11.67
300ºC- annealed	758.78	30.67	530	14.54
500°C- annealed	525.30	15.07	350	17.80
700°C- annealed	368.07	15.60	240	12.36

Yield strength against different annealing temperature of pure nickel is presented in Figure 4. The yield strength of 300 °C annealed pure nickel is higher than non-heat treated pure nickel, 500 °C annealed and 700 °C annealed pure nickel. The yield strength of the 300 °C annealed pure nickel is highest at 530 MPa and lowest for 700 °C annealed condition at 240 MPa. Young's modulus is a measure of stiffness of the material. A stiff material with a high Young's modulus shows much smaller changes in dimension when applied stress is relatively small and only cause elastic deformation (Askeland and Phule, 2006).

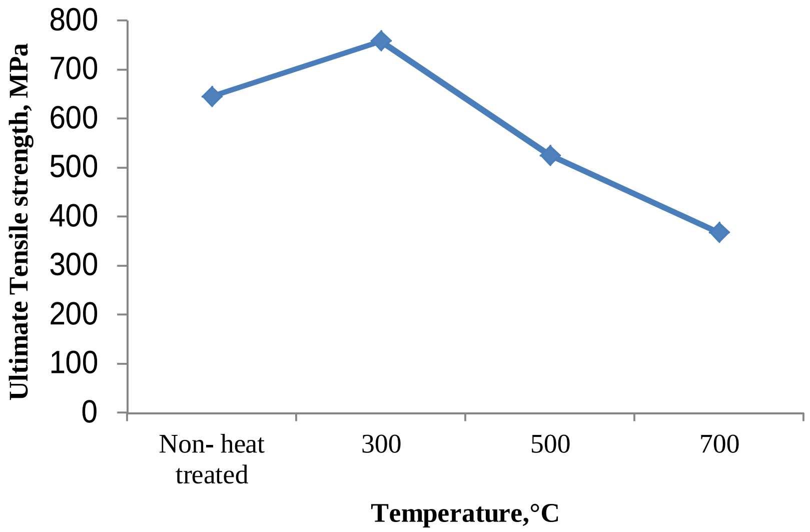

Figure 3. Ultimate tensile strength against different annealing temperature of pure nickel.

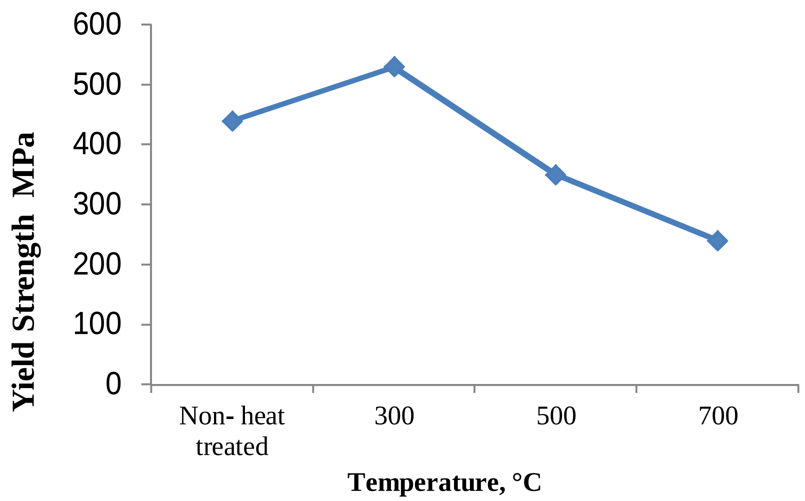

Figure 4. Yield strength against different annealing temperature of pure nickel.

Young's modulus in different annealing temperature of pure nickel is presented in Figure 5. The Young's modulus of non-heat treated pure nickel is the highest compare to annealed pure nickel. This indicates that non-heat treated pure nickel is more stiff compare to annealed. By comparing the properties of both non heat treated and annealed pure nickel with current automotive material is high strength steel, the yield strength of 300 ºC annealed pure nickel is higher compare to high strength steel. The yield strength and ultimate tensile strength of non-heat treated and 300 and 500 °C annealed pure nickel is higher than forming grade. However, the yield strength and ultimate tensile strength of non-heat treated and 300, 500 and 700 °C annealed pure nickel is lower than ultra-high-strength steel, titanium sheet, glass-reinforced plastic and carbon fibre composite. Whereas the ultimate tensile strength of ultra-high-strength steel, titanium sheet ,glass-reinforced plastic and carbon fibre composite are more than 924 MPa. The yield strength of ultra-high-strength steel, titanium sheet, glass-reinforced plastic and carbon fibre composite is more than 880 MPa. The cost of nickel (MYR/Kg) is higher than steel, aluminium and magnesium, however, lower than titanium alloy and composite. Therefore, the pure nickel can replace alternative automotive body material such as titanium and composite and reasonably steel in few cases.

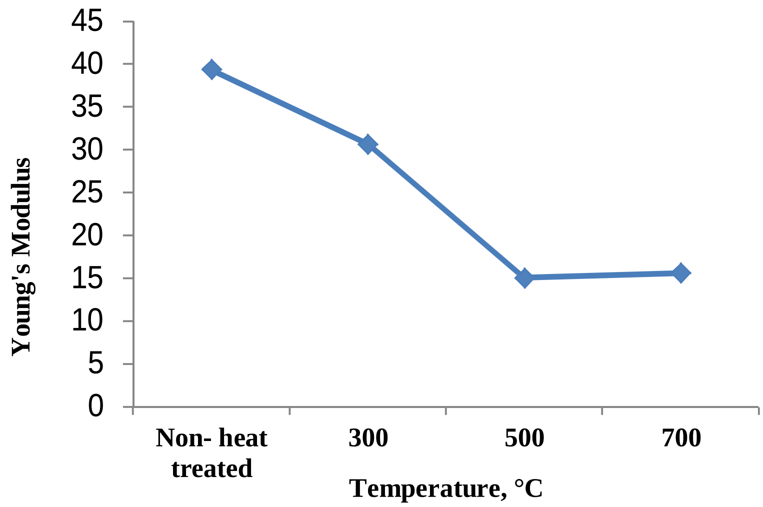

Figure 5. Young's modulus in different annealing temperature of pure nickel.

Corrosion Test

Tafel extrapolation technique has been used to obtain the corrosion rate of the nickel for various conditions of annealing temperatures. Figure 6 shows the corrosion of pure nickel for non-unannealed and annealed samples. The corrosion analysis (corrosion current density and corrosion rate) by using Tafel extrapolation techniques are tabulated in Table 3. There is no significant changes in the corrosion rates of pure nickel at different annealing temperatures. The corrosion rate of 700 °C annealed pure nickel is the highest (0.048 mm per year) compared to others. The corrosion rate of 300 °C (0.0385 mm/ year) and 500 °C (0.0266 mm/ year) is lower than non-heat treated pure nickel and 700 °C annealed pure nickel.

Table 3. Corrosion analysis by using Tafel Extrapolation technique.

Pure nickel	Area in contact, cm	Density (g/cm^3)	Total anodic current, μA	Corrosion current density, A/cm^2 (i_{corr})	Corrosion rate in 3.5% NaCl(mm/year)
Non heat-treated	1.83	8.32	7.0	3.823	0.0440
300°C- annealed	1.83	8.54	4.0	3.421	0.0385
500°C - annealed	1.83	8.89	6.0	3.925	0.0466
700°C- annealed	1.83	9.37	8.0	4.6852	0.0480

Corrosion resistance on automotive body material is an important parameter when consider its life time and maintenance. The nickel has good corrosion resistance as compare to aluminium, magnesium and iron. The ease of steel oxidation is higher. To improve the corrosion resistance to prolong automotive life, the application of coated steel sheets to automotive body parts have been extended. There are various method used for the protection of steel such as zinc coatings, paint pre-treatments, electro-priming, wax injection and adhesive. According to Hayashi and Nakagawa (1994), the coated steel sheets have difficulty in press forming, such as surface damages of plating layer, surface defects and unstable forming performance. Therefore, the nickel is good materials use as an alternative body due to it corrosion resistance.

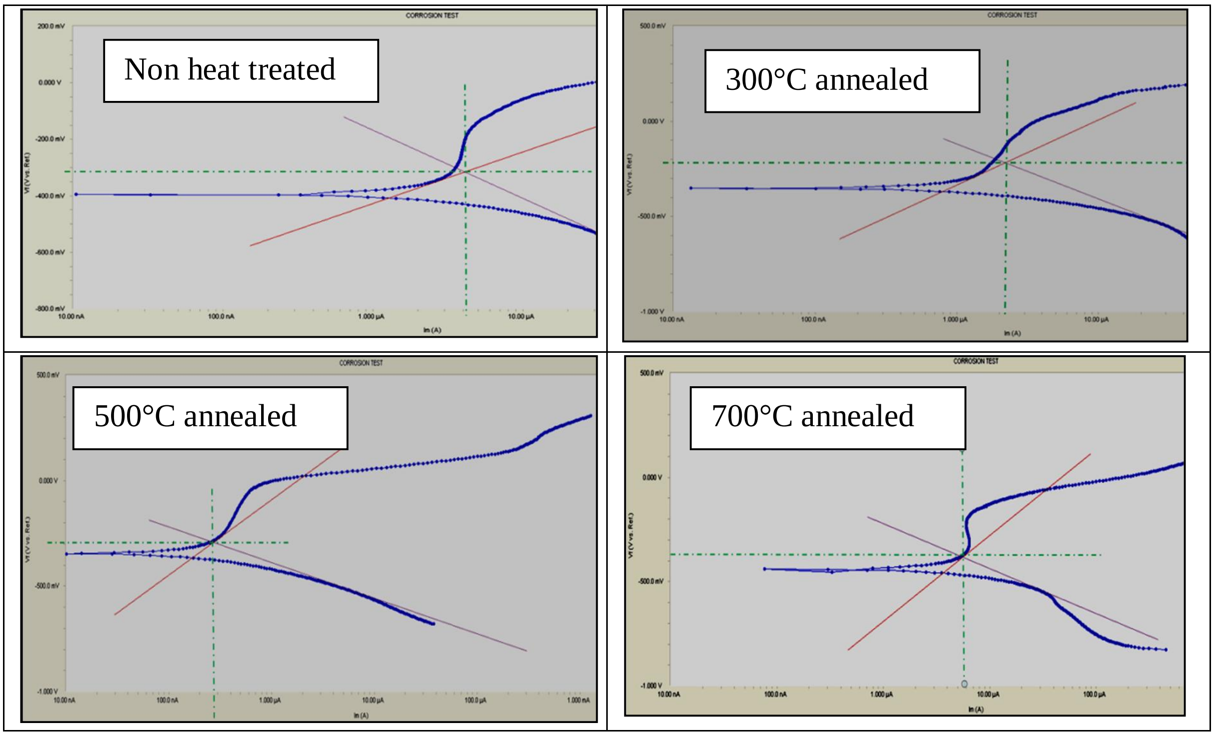

Figure 6. Tafel of both non- heat treated and annealed nickel samples.

Energy Dispersive X-Ray Analysis

The purpose of using energy dispersive X-Ray is to identify the composition of non-heat treated pure nickel and annealed pure nickel. The compositional results obtained from EDX for non-heat treated and annealed pure nickel is shown in Figure 7. It can be seen that the weight percentage and atomic percentage of non- heat treated and annealed pure nickel is not change which confirms that there is no impurity or foreign elements are present after heat treatment to the samples.

X-Ray Diffraction Analysis

The purpose of X-Ray diffraction used is to identify the crystallographic changes of the non-heat treated and annealed pure nickel. Crystallographic results obtained from X -Ray diffraction are presented in Figure 8. By using the data obtained from XRD, the grain size of the pure nickel in different annealing temperature can be calculated. The peak of pure nickel was determined from theoretical XRD lattice parameters as shown in Table 4 with the comparison between theoretical and experimental interplanar spacing of non- heat treated pure nickel sample.

Table 4. Theoretical XRD lattice parameter of pure nickel.

Pure nickel	Interplanar spacing *d* (dm)		Angle (2θ)	($h\ k\ l$)	Intensity
	Theoretical	Experimental			
Ni Cubic, *a*= 0.3524 nm	0.2034	0.2020	44.505	1 1 1	100
	0.1762	0.1750	51.844	2 0 0	42
	0.1246	0.1242	76.366	2 2 0	21
	0.1062	0.1059	92.939	3 1 1	20
	0.1017	0.1015	98.44	2 2 2	7

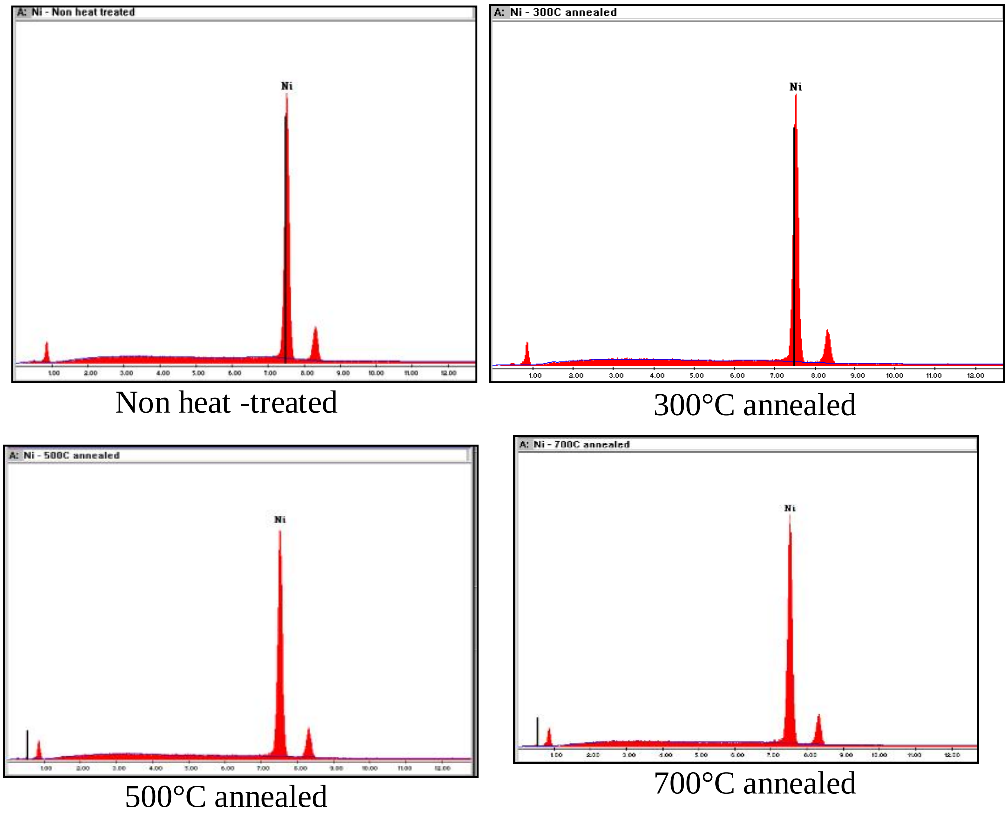

Figure 7. Compositional results obtained from EDX for non-heat treated and annealed pure nickel.

Table 5 shows the comparison lattice constant of both non- heat treated and annealed pure nickel in different peak. The theoretical lattice constant for pure nickel is 0.3524 nm. The lattice constant is calculated by Eq. (1).

$$d_{hkl} = \frac{a}{\sqrt{h^2 + k^2 + l^2}} \tag{1}$$

where, a = Lattice constant; d = Interplanar spacing, nm; (h, k, l) = Miller indices.

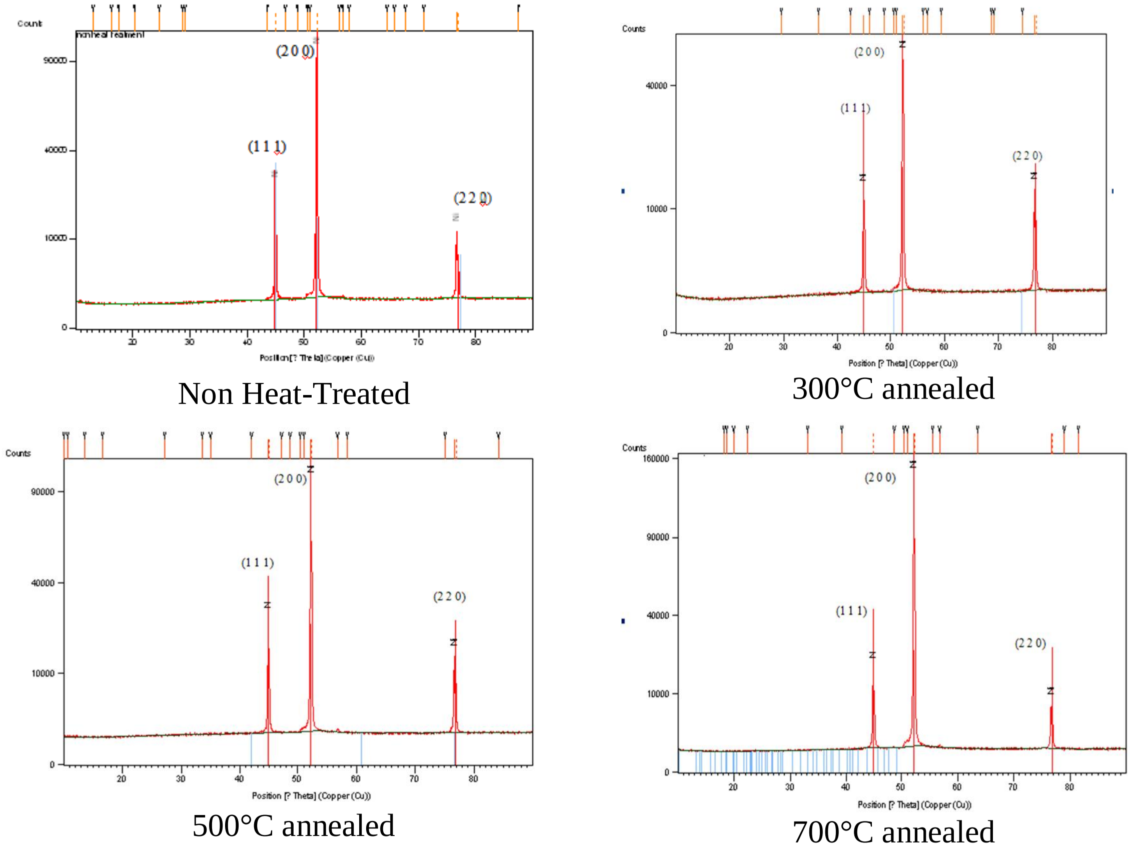

Figure 8. Crystallographic results obtained from X -Ray diffraction.

Table 5. XRD lattice parameters comparison (taking the (111), (200) and (220) - peak as reference.

Pure nickel	Lattice constant, *a*		
	(1 1 1)	(2 0 0)	(2 2 0)
Non- heat treated	0.3503	0.3502	0.3512
300°C- annealed	0.3499	0.3500	0.3511
500°C - annealed	0.3498	0.3496	0.3510
700°C- annealed	0.3494	0.3492	0.3509

The crystallography of pure nickel was confirm by X-Ray Diffraction, and it is confirmed as face centered cubic with the lattice constant in the range of 0.3492 to 0.3512 nm which almost the same with theoretical lattice constant, 0.3524nm. From Table 5, lattice constant of pure nickel is decreasing as annealed temperature increasing. The grain size of pure nickel is calculated according to Eq. (2).

$$\text{Grain Size} = \frac{0.9\lambda}{B\cos\theta} \tag{2}$$

where, λ = wavelength
B = Peak width at half maximum in radians
Θ = half of the reported peak centric

Table 6 shows the range of the grain size for both non- heat treated and annealed pure nickel. The grain size of annealed pure nickel increases as the annealing temperature increases. According to Xiao et al. (2001), the occurrence of abnormal grain growth in metals and alloys are generally related to the presence of retraining force against grain growth. The typical restraining forces are second phase particles, free surface and crystallographic texture.

Table 6. The grain size range of non-heat treated and annealed pure nickel.

Nickel	Grain size range (nm)
Non heat-treated	0.6-2.7
300°C - annealed	0.3-3.5
500°C- annealed	0.5-4.4
700°C- annealed	0.4- 12.3

CONCLUSIONS

From XRD analysis, the lattice constant of non- heat treated and annealed pure nickel is in the range of 0.3492 to 0.3512 nm, which is in good agreement with the standard value of pure nickel is 0.3524 nm. The grain size of pure nickel is gradually increasing for non-heat treated and their annealed counterpart. The hardness of annealed pure nickel does not show major changes, which are in the range of 118 to 124 HV and temperature change does not affect the hardness. The yield strength and ultimate tensile strength of annealed pure nickel decreases as the annealing temperature increases. At 500 °C annealed pure nickel, the elongation is more prominent than other samples. Therefore, 500 °C annealed pure nickels is more ductile compare to others. The corrosion rate of 700 °C annealed pure nickel is higher than others whereas the lowest corrosion rate is at 500 °C annealed pure nickel. By comparing the characteristics of both annealed and unannealed pure nickel with the current automotive material, the tensile strength of pure nickel is higher compare to aluminium, magnesium and some of the steel. Pure nickel is ductile and having good toughness with fcc structure, which makes it suitable as an automotive body material because it can also absorb energy in case of high speed crashes. The cost of pure nickel is higher than steel, but lower than some of the current automotive body materials such as titanium alloy and composite.

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