ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

MSc THESIS

Ayşe Nur ACAR

INVESTIGATING THE STRUCTURAL AND PHYSICAL PROPERTIES FOR AL-7000 SERIES PREPARED ON DIFFERENT TEMPERATURES AND PRESSURES

DEPARTMENT OF MECHANICAL ENGINEERING

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We certify that the thesis titled above was reviewed and approved for the award of degree of the Master of Science by the board of jury on //2014.

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ABSTRACT

MSc. THESIS

INVESTIGATING THE STRUCTURAL AND PHYSICAL PROPERTIES FOR AL-7000 SERIES PREPARED ON DIFFERENT TEMPERATURES AND PRESSURES

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Thermoelectricity is referred to convert from waste heat generated from many sources such as radiation, automobile exhaust gases to electricity. Via conversion of waste heat to electricity by TEP(Thermoelectric Power) of solids without generating greenhouse gas emissions , thermoelectric generators could be significant role and also TE coolers are used to make refrigerators and other cooling systems.

The main aim of this study is to investigate the structural and thermoelectric properties of Alumix 431 (Al-5.5Zn-2.5Mg-1.5Cu) material which is the Al7xxx series alloy and prepared utilizing the traditional press and sintering process in various pressure and temperatures. Due to the goal, the structural properties of materials were investigated on the optical, SEM figures and hardness testing measurement results; the thermoelectric properties were measured on the PPMS (Physical Property Measurement System) Machine at temperature range 5-300K. The obtained experimental results show that at temperature range of 285-295 K, the maximum electrical resistivity and electrical conductivity were acquired 0.161Ωm and 24.96W/Km respectively, and the Seebeck Coefficient values changed mostly negative sign to positive sign due to dominate from carriers. Also, it was determined as 5.65×10^{-6} of the maximum figure of merit at 300K temperature.

Key Words: Al 7xxx alloys, Alumix 431, Structural and Thermoelectric Properties

ÖZ

YÜKSEK LİSANS TEZİ

FARKLI SICAKLIK VE BASINÇLARDA HAZIRLANAN Al 7xxx
SERİLERİNİN YAPISAL VE FİZİKSEL ÖZELLİKLERİNİN
ARAŞTIRILMASI

Ayşe Nur ACAR

ÇUKUROVA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ
MAKİNA MÜHENDİSLİĞİ ANABİLİM DALI

Termoelektriklik, radyasyon, otomobil egzos gazı gibi kaynaklardan oluşan atık ısıyı elektriğe çevrilmesi olarak tanımlanır. Seragazı gaz emisyonları olmadan, katılardaki TEP(termoelektrik güç) aracılığıyla, atık ısının elektriğe çevrilmesiyle, termoelektrik jeneratörler önemli bir rol oynar ve ayrıca termoelektrik soğutucular, buzdolabı ve diğer soğutucu sistemlerin yapımında kullanılır.

Bu çalışmanın asıl amacı, Al 7xxx serisi alaşımı ve farklı basınç ve sıcaklıklarda geleneksel pres ve sinterleme prosesi sonucu üretilen Alumix 431 alaşımının yapısal ve termoelektrik özellikleri incelemektir. Yapısal özellikler; optik, SEM resimlerinde ve sertlik test ölçüm sonuçlarında incelenmiş, termoelektrik özellikler 5-300K sıcaklık aralığında PPMS(Fiziksel Özellik Ölçüm Sistemi) cihazında ölçülmüştür. Elde edilen deneysel sonuçlar; 285-295K sıcaklık aralığında maksimum elektriksel direnç ve iletkenlik sırasıyla 0.161Ωm and 24.96W/Km olarak elde edildiğini, Seebeck katsayısının taşıyıcılardan dolayı çoğunlukla negatif değerden pozitif değere değiştiğini göstermiştir. Ayrıca, maksimum performans katsayısı 300 K sıcaklıkta 5.65 $\times 10^{-6}$ olarak saptanıştır.

Anahtar Kelimeler: Al 7xxx alaşımları, Alumix 431, Yapısal ve Termoelektrik Özellikler

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

S	:	Seebeck coefficient
α	:	Seebeck coefficient
ΔV	:	Variance of thermoelectric voltage
ΔT	:	Variation of temperature range
T	:	Temperature
ρ	:	Electrical resistivity
σ	:	Electrical conductivity
κ_{total}	:	Total thermal conductivity
κ_e	:	Electronic thermal contribution
κ_l	:	Lattice thermal contribution
$\kappa_{bipolar}$	:	Bipolar thermal contribution
ZT	:	Dimensionless figure of merit
Z	:	Figure of merit
P	:	Thermoelectric power
k_B	:	Botzmann constant
e	:	Charge of electron
n	:	Carrier concentration
μ	:	Charge carrier mobility
L	:	Lorenz factor
L_{ph}	:	Phonon mean free path
ν	:	Electron velocity
ν_F	:	Fermi velocity
ν_S	:	Sound velocity
c_v	:	Heat capacity at constant value
Λ	:	Electron mean free path
r	:	Scattering factor
m	:	Carrier effective mass
E_F	:	Fermi energy
E	:	Carrier energy

l	:	Free path length of the scattering
s	:	Scattering mechanism constant
μ_H	:	Temperature dependence of the electron Hall mobility
R_H	:	Hall coefficient
$\rho_{M(t)}$	:	The resistivity of the matrix phase
ρ_i	:	The initial resistivity value after quenching
ρ_s	:	The maximum resistivity value
$\rho_{(t)}$	:	The measured instantaneous resistivity value
ρ_o	:	The resistivity of the alloy
$\sigma_{M(t)}$	:	The conductivity of the matrix phase
$\chi_{Zn(t)}$	:	The concentrations of the Zn Element in the matrix phase
$\chi_{Mg(t)}$	:	The concentrations of the Mg Element in the matrix phase
t	:	Ageing time
t_c	:	Diffusion condition

1. INTRODUCTION

Powder Metallurgy is a method by which fine powdered materials are mixed, pressed into a desired shape (compacted) and then sintered in a controlled atmosphere to bond the conducting particles and to constitute wanted particles (Black and Kosher, 2008).

Powder metallurgy is related to manufacturing of metal powders and conversion of them to useful shape (Ramakrishnan, 1983). In this method, mechanical and thermoelectric properties are exceedingly related to the microstructures of materials and microstructure formation. In this method, it is acquired an improved mechanical property such as high strength and hardness (Lim et al., 2006) (Yang et al., 2009). Manufacturing of materials via powder metallurgy methods also achieves the increase of figure of merit because of grain purification as well as higher compressive strength (Bhuiyan, 2011).

1.1. The Basic Principle Of Thermoelectricity

Conversion of different types of 'subgrade' heat such as industrial waste heat, the vehicle exhaust gas heat, solar and geothermal energies is happening more significant owing to environmental interests (Xu et al., 2012; Rubi et al., 2014). Thermoelectric materials and devices are suitable for this conversion. These materials and devices convert waste heat into electricity via the thermoelectric power of solids (Tritt et al., 2006). Thermoelectric generators can be applied to transforming heat produced by sources such as exhaust gases to electricity using the Seebeck effect. This effect is the transformation of temperature varied directly electricity. As a generator is operated, one side of the tool is heated to a temperature greater than the other side, then all a different in a voltage will increase between the two sides. These thermoelectric generators are also defined Seebeck generators. In contrast thermoelectric coolers can be utilized to make refrigerators and other cooling systems. These devices operate using the Peltier effect and produce heat flow

between linking of two different types of material. These coolers are also defined Peltier coolers. The Seebeck and Peltier effects will be explained below.

Owing to their reliability, operation the unattended in hostile environments and environmental friendly, thermoelectric materials and devices are used in infrared sensors and satellites. The disadvantage of these materials is the operating of low efficiency limited applications.

In the below fig. 1.1 presents that the various energy applications of thermoelectric materials.

Power (Watts)

10k — Large scale waste heat recovery, e.g., transportation vehicles
1k
Microelectronics, e.g., CPU cooling
100
10 — Consumer applications, e.g., Wine coolers
1
Space Power and cooling, e.g., Voyager
100m
10m
Remote wireless sensors, e.g., networks
1m
100μ — Biomedical devices, e.g., pacemakers
10μ
Low-power applications, e.g., wrist watches
1μ
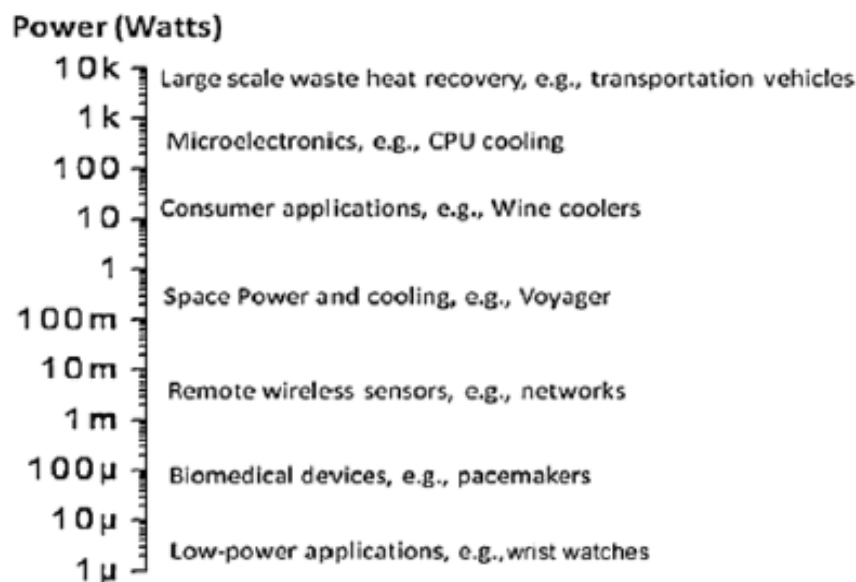
Figure. 1.1. Various energy conversion applications of thermoelectric materials (Radousky and Liang,2012)

In waste heat recovery, There are issues in the way of automobiles or other transportation vehicles, besides utilize in oil refineries while other issues consist of heat distribution e.g. in microelectronics- where leakage currents in transistors exponentially increase with temperature. These are based on the both energy conservation and generation. Spite of this situation, because of their low efficacy, the utilization of thermoelectric materials is not as wide as hoped.   Via thermoelectric and thermionic materials, The energy conversion between thermal and electrical forms is to be more efficient in materials consisting materials and

successful application of nanostructured thermoelectrics, the materials are hoped to applied a wide range of implementations.
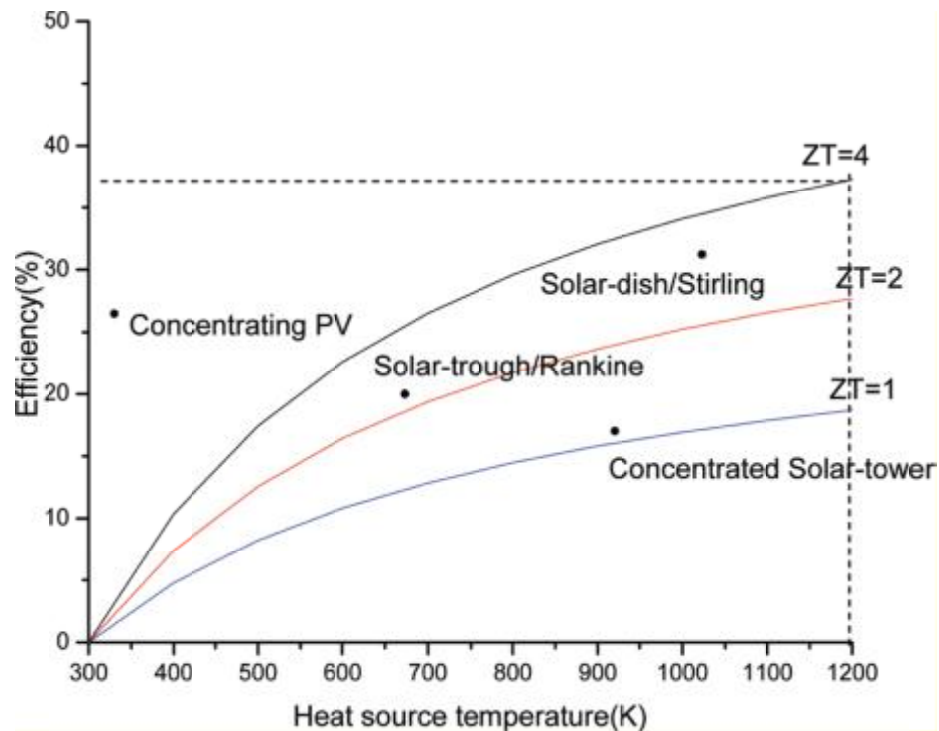
Figure.1.2. For different values of ZT, thermoelectric conversion efficiencies related to function of temperature differentials (Xie and Gruen, 2010)

Figure 1.2. indicates the manner in which conversion efficiencies of thermoelectric materials related to ZT when plotted as a function of heat source temperatures, under the assumption that the temperature of the cold side is maintained at 300 K. The conversion efficiency of thermoelectric materials must be 30%-40% in order to compete with state of- the-art solar-thermal technologies related to on the electromagnetic induction method. Between the hot and cold ends of a thermopile, this needs ZT = 4 and a large temperature differential. (Xie and Gruen ,2010).

There are three fundamental effects of thermoelectric materials: the Seebeck effect, the Peltier effect, the Thomson effect. As described above Seebeck effect which discovered by Johann Seebeck in 1821 defines the phenomena that a conductor creates a voltage as related to temperature variance.

$$V = \alpha \Delta T \quad \rightarrow \quad \alpha = S = \frac{\Delta V}{\Delta T} \tag{1.1.}$$

Where S,α is defined to Seebeck coefficient, ΔV and ΔT is variance of thermoelectric voltage and temperature range respectively.

The Peltier effect refers to the temperature variations inducted by voltage gradience. Due to this property of Peltier effect, it is reversal effect of Seebeck effect. The Thomson effect depends on both the reversible thermal gradient and electric field in a uniform conductor.(Figure 1.3.)
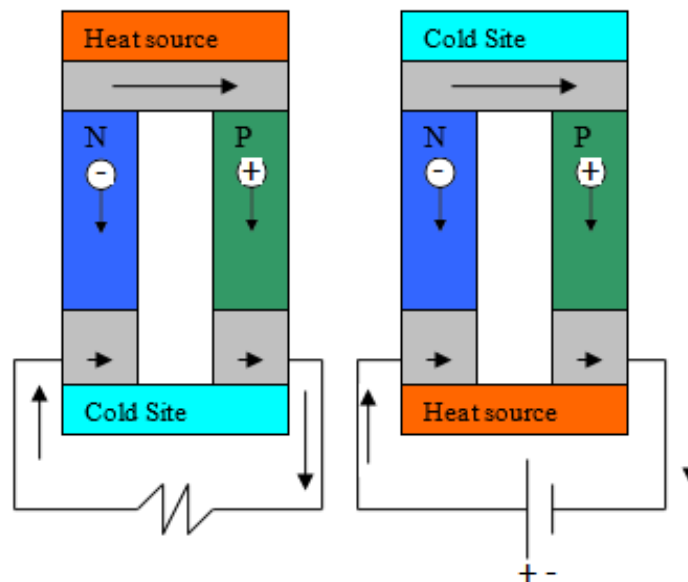
Figure 1.3. An illustration of TE effect

1.1.1. The Electrical Conductivity

Electrical conductivity is utilized to quantify the electrical character of material. It is simply the reciprocal relationship between electrical conductivity and resistivity;

$$\sigma = \frac{1}{\rho} \tag{1.2.}$$

and is indicative of the simple with which a material is capable of conducting an electric current. The units for σ are reciprocal ohm meters (Ωm) or mho/m.

Solid materials show an surprising range of electrical conductivities. Materials are good conductivities, typically having conductivities on the order of $10^7(\Omega m)^{-1}$, insulators have very low conductivities ranging between 10^{-10} and $10^{-12}(\Omega m)^{-1}$. Materials with intermediate conductivities, usually from 10^{-6} to $10^4(\Omega m)^{-1}$ are referred as semiconductors (Callister and Retwisch, 2012).
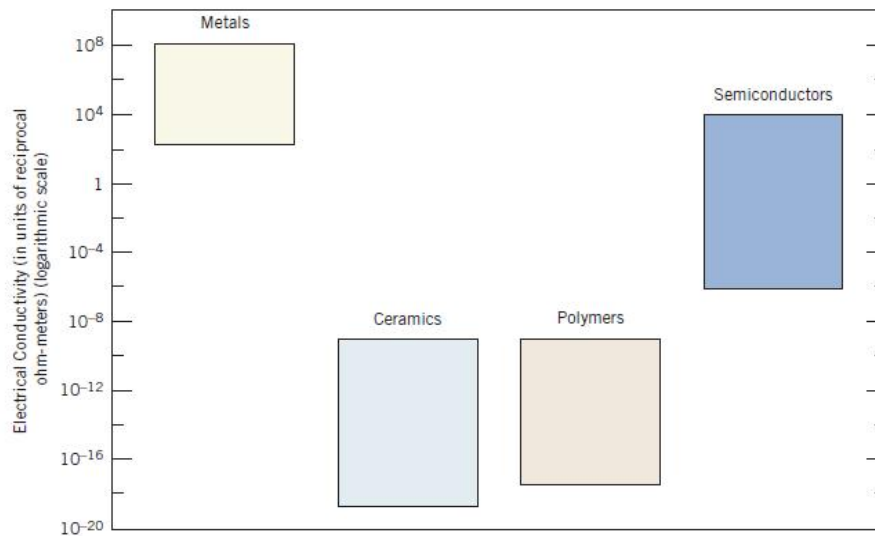
Figure 1.4 Bar chart of room temperature electrical conductivity ranges for metals, ceramics, polymers, and semiconducting materials (Callister and Retwisch, 2012)

1.1.2. Electrical Resistivity

One of the most significant electrical characteristics of a solid material is the simple with which it transmits an electric current. Ohm's law depends on the current I- or time rate of charge passage to the applied voltage V(V=IR, where R is the resistance of the material through which the current is passing.) R is affected by specimen configuration and for many materials in independent of current (Callister and Retwisch, 2012) .
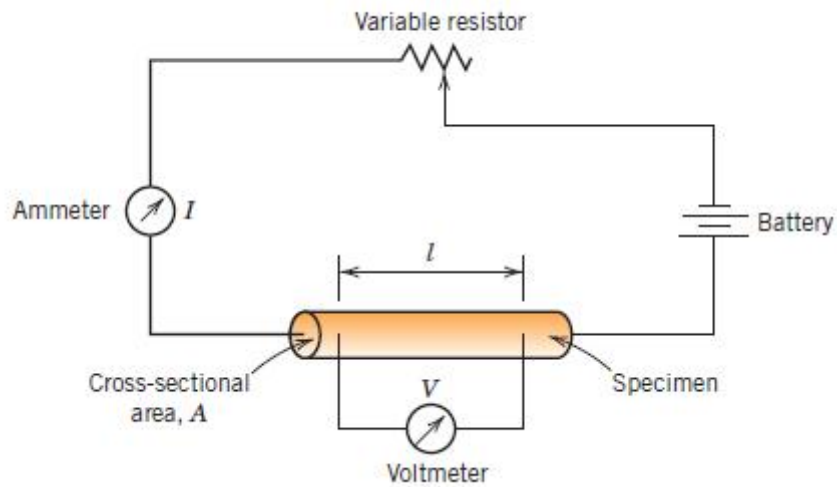
Figure 1.5. Schematic representation of the apparatus used to measure electrical resistivity (Callister and Retwisch, 2012).

The electrical resistivity, ρ, is depended on resistance specimen cross sectional area (A) and distance between measuring points and independent of specimen geometry but according to through the expression.

$$\rho = R\frac{A}{l}$$ (1.3.)

A, l are stated the cross-sectional area perpendicular to the direction of the current, the distance between the two points at which the voltage is measured, respectively. The units for ρ are ohm.meters (Ω.m) (Callister and Retwisch, 2012).

1.1.3. Thermal Conductivity

Thermal conduction is the transport of thermal energy from high to low temperature regions of a material. The property characterizes the ability of a material to transfer heat (Callister and Retwisch, 2012).

$$q = k\frac{dT}{dx}$$ (1.4.)

Where q is heat flux per unit time per unit area (area being taken as that perpendicular to the flow chart), k is the thermal conductivity, dT/dx is the temperature gradient through the conductivity medium.

In solid materials, heat is transisted by both lattice vibration waves (phonons) and free electrons. A thermal conductivity is related with each of these mechanisms, and the total conductivity is the sum of the two contributions, or

$$\kappa = \kappa_e + \kappa_l \qquad (1.5.)$$

κ_e and κ_l is stated the lattice vibration and electron thermal conductivities, respectively.

The κ_l contribution occurs from a net movement of phonons from high- to low-temperature regions of a body across which a temperature gradient exists. A gain in kinetic energy is clarified to the free electrons in a hot region of the specimen. Then, they migrate to colder areas. The areas are to where transferred of some of this kinetic energy to the atoms (as vibrational energy) as a result of collisions with phonons or other imperfections in the crystal (Callister and Retwisch, 2012).

For relatively pure metals, they have high thermal conductivity because of the large numbers of free electrons and the efficiency with which these electrons transport thermal energy. On the contrary, ceramics and polymers have low thermal conductivity due to the low free-electron concentrations and predominating phonon conduction (Callister and Retwisch, 2012).

1.1.4. Seebeck Coeficient

Owing to conduction, the transfer of heat energy by microscopic diffusion and collisions of particles or quasi-particles within a body because of due to a temperature gradient, heat flows through a solid material. The heat flux is the rate of heat transfer per unit area through a material, in order words, is directly proportional to the temperature gradient. There are different mechanisms which can transfer heat in a material. The first mechanism is occurred through vibrations of the internal

structure of the material, such as vibrations of the crystal lattices or individual atoms, while the other mechanism is occurred through electron transport (Kim et al., 2012).

In a material having electrically conductive, electrons can carry heat from one end to another giving rise to the Seebeck effect. To stop the drag and continue equilibrium, a force is required. This force takes the form of a voltage potential that develops to stop the drag of electrons. The magnitude of this Seebeck effect is characterized by the Seebeck Coefficient. The coefficient has units of voltage per unit temperature generally stated in microvolts per Kelvin (Kim et al., 2012).

The magnitude of this effect is quantified by the Seebeck coefficient. Seebeck Coefficients have units of voltage per unit temperature, usually expressed in microvolts per Kelvin, and can be calculated using Equation 2:

$$S = \Delta V / \Delta T \qquad (1.6.)$$

Where ΔV is stated the voltage difference between the hot and cold sides of a thermoelectric material and ΔT is the change in temperature between the sides. Related to whether the mobile charges are holes or electrons, the can have a positive or negative value, therefore giving the Seebeck coefficient a positive or negative value (Kim et al., 2012).

1.1.5 The Figure Of Merit

A thermoelectric tool includes of an element put between a heat source i.e. with regard to waste heat generation and the heat sink. From the source to the sink, heat transfer is through the carriers (electrons) motion or through the lattice.

The carrier transport occurs in a development of a potential difference. This potential difference (ΔV) is referred as the Seebeck voltage. As the showed on the formula of S above, the Seebeck coefficient is the ratio of Seebeck voltage (ΔV) to the temperature variance ΔT.

The combination of three effects (Seebeck effect, Peltier effect and Thomson effect) is stated to Kelvin Relationships. This feature represent properties of three

effects thus it is called as figure of merit by researchers.(Du and Wen, 2011) The efficiency of thermoelectric devices is characterized by the dimensionless figure of merit (ZT) of thermoelectric materials.

$$ZT = \frac{S^2 T}{\rho \kappa_{total}} = \frac{S^2 \alpha T}{\kappa} = \frac{\alpha^2 \sigma}{\kappa} \qquad (1.7.)$$

In above equation (3.2);T, ρ, κ$_{Total,}$ are referred to the average operating temperature between the hot and cold sides, electrical resistivity, total thermal conductivity respectively.

Table 1.1. shows comparison of thermoelectric properties of metals, semiconductors and insulators at 300K.

Table 1.1. Comparison of Thermoelectric Properties of metals, semiconductors and insulators (Zheng, 2008)

Property	Metals	Semiconductors	Insulators
S(μVK^{-1})	~5	~200	~1000
σ(Ω^{-1}cm^{-1})	~10^6	~10^3	~10^{-12}
Z(K^{-1})	~3×10^{-6}	~2×10^{-3}	~5×10^{-17}
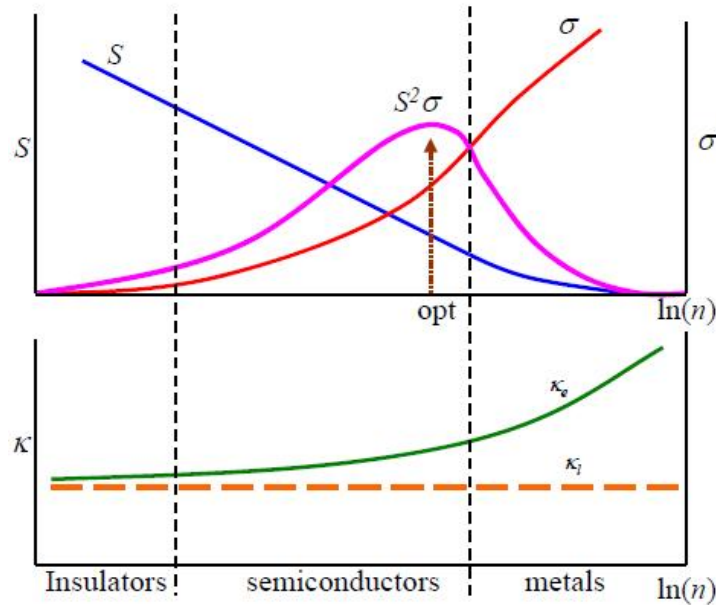
Figure. 1.6. Seebeck coefficient S, electrical conductivity σ, $S2\sigma$, and electronic (κe) and lattice (κ_l) thermal conductivity as a function of free-charge-carrier concentration n (Zheng et al., 2008)

Table 1.1. is indicated the comparison of thermoelectric properties of metals, semiconductors and insulators at 300K and figure 1.4. is illustrated the Seebeck coefficient S, electrical conductivity σ, $S^2\sigma$, and electronic (κ_e) and lattice (κ_l) thermal conductivity as a function of free-charge-carrier concentration n.   It is apparent that metals have very good electrical conductivity, but their very low Seebeck coefficient and large thermal conductivity . thus metals is not the most desired materials for TE applications.   With large band gap, for ınsulators they have large Seebeck coefficient (~1000μV/K), while they posses low electrical conductivity resulted from a small thermoelectric power ($S^2\sigma$), and small figure of merit(Z) (~5×10^{-17}) according to the metals. The optimal thermoelectric materials have a large value of $S^2\sigma$, thus the materials are located in the region near the crossover   between the semiconductor and metals   and have optimized carrier concentration of 1×10^{19}cm^{-1} (Zheng et al., 2008).

1.1. The Wiedemann -Franz Law

A high quality thermoelectric material requires a high electrical conductivity and thermopower and the low thermal conductivity. The electrical conductivity and thermopower combine into the quantity $P=\sigma S^2$ referred as the 'power factor' due to their electronic properties (Dmitriev and Zuyagin, 2010). The Wiedemann-Franz law defines that the electronic contribution to the thermal conductivity is proportional relationship to the electrical conductivity of the materials (Alaam and Ramakhrisna, 2013).

$$\frac{\kappa_e}{\sigma} = LT = \left(\frac{\pi^2}{3}\right)\left(\frac{k_B^2}{e^2}\right)T \tag{1.8.}$$

$$\kappa_e = L\sigma T = n_e\mu LT = \frac{1}{3}c_v v\Lambda \tag{1.9.}$$

$$\kappa_{ph} = \frac{1}{3}v_s c_v L_{ph} \tag{1.10.}$$

$$L_0 = \frac{\pi^2}{3}\left(\frac{k_B}{e}\right)^2 = 2.44 \times 10^{-8}\text{W}\Omega K^{-2} \tag{1.11.}$$

$$= 2.44 \times 10^{-8}\frac{V^2}{K^2}$$

$$L_0 = 2\left(\frac{k_B}{e}\right)^2 = 1.48 \times 10^{-8}\frac{V^2}{K^2} \tag{1.12.}$$

Where k_B is defined to the Boltzmann constant, e is the charge of electron, n is the carrier concentration, μ is the charge carrier mobility, L is the Lorenz factor c_v is the heat capacity at constant value, v_s is the velocity of sound, L_{ph} is the phonon mean free path, v is the electron velocity that can be assumed to be Fermi velocity v_f, and Λ is the electron mean free path, σ is the electrical conductivity and T is referred to the temperature in Kelvin. (Fergus, 2012) (Ruoho, 2012), (Tritt, 2002)

The Lorenz factor is constant only for materials and changes specifically with carrier concentration. A wide consideration of undetermination in electronic contribution happens in low carrier concentration of materials where the Lorenz factor is the reduced via approximately 20% from the free-electron value. In addition, the undetermination in κ_e is formed from combined conduction. The conduction reveals a bipolar term into the term conductivity (Snyder and Toberer, 2008).

c_υ and υ_s are generally temperature independent for T>300K, thus at high temperatures.

$$\kappa_{bipolar} = \kappa_{bi} = \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (1.13.)$$

$$\sigma_e T \left(\frac{k_B}{2}\right)^2 \left(\frac{(2r+5+n_g)^2}{1+e^{n_f}e^{n_g}\left(m_e^*/m_h^*\right)^{3/2}\left(\mu_e/\mu_h\right)^{3/2}} \right)$$

In the above equation (1.8.) r, m is stated as scattering factor and carrier effective mass.

To success effective thermoelectrics, infamous way is replacing of bipolar effect, when two types of carriers are present. The significant effect is the conduction of the heat from hot side to cold side throughout lack-net-current, the origin of κ_{bi}.(Alaam and Ramarkrishna, 2013)

In a n-type material, the bipolar effect could be restrained using following conditions;

i)   The external carrier concentration are increased (i.e. through increasing the Fermi energy E_F),

ii) The band gap E_g are enlarged,

iii) The ratio of m_e^*/m_h^* or μ_e/μ_h are increased.

The total thermal conductivity is consistent of the thermal conductivity arised from the movement of the charge carriers themselves; κ_e referred the electronic contribution, and thermal conductivity arisen from lattice vibrations, κ_l defined the lattice contribution (Dmitriev and Zvyagin, 2010).

According to the Wiedemann-Franz law; thermoelectric dimensionless figure of merit can be maximized through maximizing the electric conductivity and minimizing thermal conductivity(Dmitriev and Zvyagin, 2010).

$$ZT = \frac{S^2 T}{\rho \kappa_{total}} = \frac{\rho^2 / L}{1 + \frac{\kappa_l}{\kappa_e}} \tag{1.14.}$$

The Wiedemann-Franz law restricts the ratio of the electronic contribution to the thermal conductivity and electrical conductivity of metal(Nikiforov et al.). Whereas revealing a core materials debate for succeeding high thermoelectric efficiency. For metals, the Seebeck coefficient principally specified ZT, with either very high electrical conductivity or very low lattice conductivity as seen equation (1.14.) where $\kappa_l / \kappa_e \ll 1$ (Snyder,2008).

In ZT values, the energy carriers such as electrons and holes contribute to electric conductivity, electronic thermal conductivity, whereas the phonons also contribute to the electronic lattice conductivity.

Due to high values of ZT, it is required to acquire both high Seebeck coefficient and the electrical conductivity, and low thermal conductivity. These properties are interconnected to each other. As σ typically increases, S decreases and κ_{Total} increases.

    i) Low efficacy (with ZT<1) of thermoelectric tools has largely restricted to their applications,

    ii) ZT=1 is a maximum limit

    iii)In ZT>1 cases, as ZT increases, the new thermoelectric applications show up.

Table 1.2. Examples on the Required device ZT (Vining, 2009)

Examples	Required device ZT
Solar thermal 'engine' replacement	>8–20
Industrial waste heat, geothermal bottoming cycles	>4
Vehicle waste heat, car cooling/heating, home co-generation	>1.5–2
Remote power, 'personal' micropower, all existing applications	>0.5–1

 The most widely promising examples;   vehicle waste heat is appeared.(Table 1.2.)

The Wiedemann- Franz law only performs to thermal conductivity via charge carriers. The carriers occur one-third of total electrical conductivity in thermoelectric materials (Ruoho, 2012).

With phonon scattering via adding flaws, the reducing of κ_{total} happens in reducing in both carrier mobility and electrical conductivity(Alaam and Ramakrishna, 2013) For semiconductors, the law is stated following equation;

$$\frac{\kappa_e}{\sigma} = (s + 2)\left(\frac{k_B}{e}\right)^2 T \qquad (1.15.)$$

Where s is the scattering parameter referred as

$$l = l_0(T)E^s \qquad (1.16.)$$

l is the defined as free path length (mean free path) of the scattering, E is the carrier energy, s is dependent on the scattering mechanism constant. For acoustic phonon scattering, optical phonon scattering (alloy disorder scattering), ionized

impurity scattering, s is given values in -1/2, 1/2 and -3/2 respectively (Dughaish, 2002).

κ_l is referred as function of the acoustic phonon scattering processes like phonon-phonon scattering, phonon-electric carrier scattering and phonon-impurity scattering whereas κ_e will be influenced via nanostructing if σ varies because of carriers scattering (Qintana, 2013). Both phonons and charge carriers can subjected to distribution, because of other phonons, lattice holes, impurities, electrons, grain boundaries, interfaces. Thus distribution ends in variable of thermal conductivity.

The scattering mechanisms will affect the phonon mean free path. For nanaostructured materials; the thermal conductivity can be given smaller values their bulk counterparts. Because, with mean free paths, the effective phonon scattering of acoustic phonons is longer than the characteristic diensions of the nanostructured materials. This   process is referred to phonon-boundary scattering. Electric carriers transport could remain unmoved, while phonons can be scattered in nanostructured materials. Because, their mean free path is different orders of magnitude smaller than phonons (Qintana, 2013).

1.2. The Hall Effect

The Hall Effect discovered by Dr. Edwin Hall in 1879 is defined to an occuration of transverse electric field vertical to both magnetic field and the original current flow, when a current-carrying conductor is putting into a magnetic field. In other words, the mobile charges formed the current are distorted sidewise and stepped up a potential variety between the two sides of the conductor when a magnetic field is performed vertircular to a current in any conductor (Honeywall) (Grubbs,1959).

A thin sheet of semiconducting material referred to Hall element through which a current is run. When magnetic field is absence, output connections are vertircular to direction of current. if the Hall voltage is measured, the output is given zero value, when magnetic field is absence, and, non-zero will be seen at each output terminal (Honeywell).

A method of measuring both specific resistivity and Hall Effect of flat specimens of optional shape is dependent on a theorem. The theorem is defined to hold for a flat specimen of selective shape. The contacts are enough small and locate at the circuit of the specimen (Honeywell).
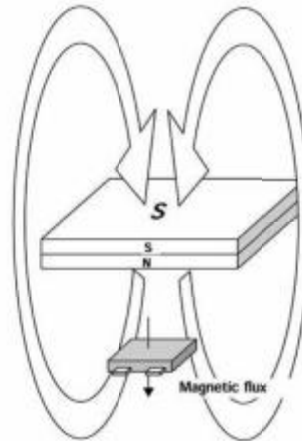
Figure 1.7. A Hall voltage generated from current flow in the semiconductor material (Rohm)

Both the specific resistivity and the Hall effect of the flat specimens selective shape can be measured non-knowing the current profile, if the below conditions are summed up;

  i)   The contacts are at the circuit of the specimens
  ii) The contacts are equal small
  iii) The contacts are in homogeneously thickness
  iv) Specimen surface is one by one joined (Pauw, 1959)

In the Hall Effect, to maximize ZT of thermoelectric material, both α and σ will be low.

$$\mu_H = \frac{R_H}{\rho} \tag{1.17.}$$

In the above equation (1.17.); μ_H and R_H is defined to temperature dependence of the electron Hall mobility and Hall coefficient respectively(Pagava and Chkharishvili,2004).

1.4.Thermoelectric Materials And Manufacturing Methods

Thermoelectric materials are classified by the temperature interval of their application:

i) Bi_2Te_3 and its alloy: They ordinarily work around room temperature and have a maximum operating (working) temperature,

ii) PbTe based alloys and TAGS(Te-Ag-Ge-Sb): they work intermediary temperature between 600-900K,

iii) Si-Ge alloys: they work at high temperature(1000-1300K) and utilize in power generation tools.

Researchers study other materials such as Ca, Al etc. also.

The discovery of thermoelectric materials started from traditional semiconductors such as group III-V(e.g. InSb), IV-IV(e.g. SiGe), group IV chalcogenides(e.g. PbTe), group V chalcogenides (Bi_2Te_3,Sb_2Te_3) to recent complex materials (i.e. skutteridites, clathrates, half Husler alloys, complex chalcogenides, cobaltes and so on) and low-dimensional thermteroelectrical materials such as quantum well, quantum dot, nanowires, molecular junctions.
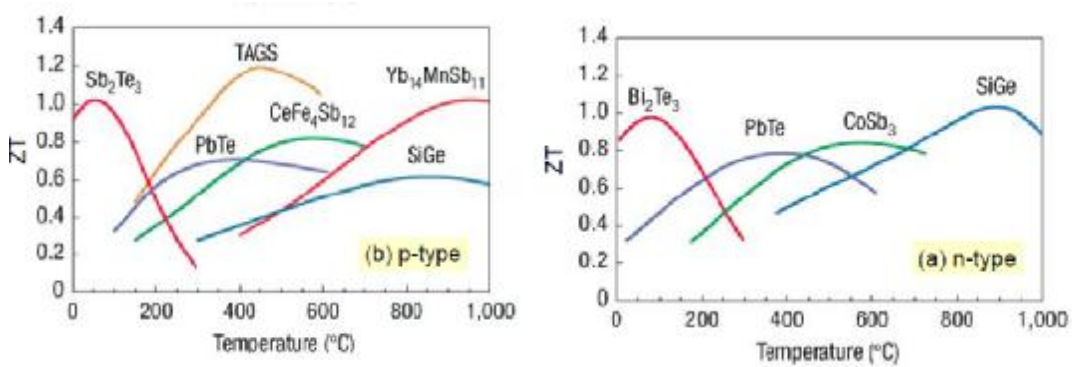
Figure 1.8. Temperature dependent on the Figure of merit (ZT) curves of p-type and
            n-type materials (Snyder and Toberer, 2008)

The commonly utilized thermoelectric materials are alloys of Bi_2Te_3 and Sb_2Te_3. Bi_2Te_3 alloys have been demonstrated to have the greatest figure of merit for both n- and p-type TE systems, for near-room-temperature applications such as refrigeration and waste heat recovery up to 200°C. Besides a reduction in lattice thermal conductivity, alloying with Sb_2Te_3 and Bi_2Se_3 permitted for the fine tuning of the carrier concentration. Whereas n-type compositions are close to $Bi_2(Te_{0.8}Se_{0.2})_3$, the most widely studied p-type compositions are near $(Sb_{0.8}Bi_{0.2})_2Te_3$. For single and polycrystalline materials peak ZT values are typically varied in the range of 0.8 to 1.1 with p-type materials achieving the highest values (Figure 1.8.)

The manufacturation methods of TE materials can be classified with their categories:

-crystal growth of bulk materials from melts

-thin –film preparation techniques

-powder based techniques

In the crystal growth techniques of thermoelectric materials, many various parameters affect the features of thermoelectric materials. A significant parameter of those is the microstructure, specifically the grain boundary. Their effects can be decreased or even eliminated through utilizing of single crystals. This case will be revealed the intrinsic feature of the compounds (Wagner et al. 2014). Throughout

various crystal planes, carrier transports are apparent. The prior-growth of a certain crystal planes would possess a great influence on thermoelectric performance (Zhu et al. 2014).

Thin film technique is a method to enhance the thermoelectric properties of thermoelectric materials via the increasing both the electrical conductivity and Seebeck coefficient. Because the technique improves the stronger quantum confinement effect. The enhanced thermoelectric properties of the film offer a huge potential in miniaturization sensors, micropower source of the film thermoelectric devices. (Zheng et al. 2014)(Lee et al. 2012). To enhance of both the electrical conductivity and Seebeck coefficient is difficult due to dependent on the figure of merit. Thin film techniques of materials are pointed out sol-gel, PLD, MOCVD CVD etc.(Castro et al., 2014)

Powder metallurgy method consists of milling, pressing and sintering processes and provides in producing such nanostructured thermoelectric materials (Lu and Liao,2013). Powder metallurgy is utilized to obtain improved mechanical properties such as higher compressive strength (Lim et al., 2006)(Bhuiyan, 2011).The same case is seen in the increasing of the figure of merit, whereas decreasing in the lattice conductivity because of grain purifications. The powder can be prepared gas atomization, mechanical alloying, chemical reactions besides other special methods based on the material, economy, their application areas(Bhuiyan, 2011)

2. PREVIOUS STUDY

2.1. The Thermoelectric Properties of Materials Produced By Powder Metallurgy

Powder metallurgy is related to manufacturing of metal powders and conversion of them to useful shape (Ramakrishnan, 1980). This method includes milling, pressing and sintering processes and widely applied in manufacturing nanostructured thermoelectric materials (Lu and Liao, 2013) (Figure 2.1.). In this method, it is acquired an improved mechanical property such as high strength and hardness (Lim et al., 2006) (Yang et al., 2009). Manufacturing of materials via powder metallurgy methods also achieves the increase of figure of merit because of grain purification as well as higher compressive strength (Bhuiyan, 2011).
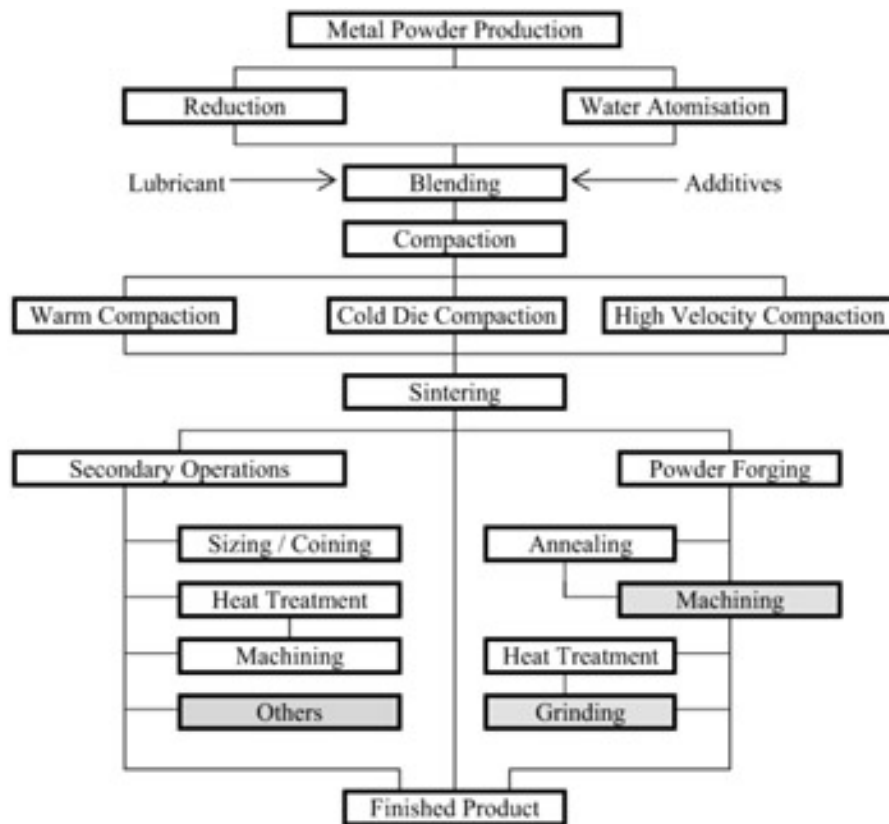
Figure 2.1. Schematic of the powder metallurgy processing steps.

Mechanical and thermoelectric properties are exceedingly related to the microstructures of materials and microstructure formation is affected via the hot consolidation process. For this reason, this case plays an important role to analyze and establish the connection between the material processing parameters, microstructures and their properties (Bhuiyan, 2011). As a known, microstructure of materials is qualified via particle size, shape, content, state of dispersed phases and the homogeneous grain boundary (Yang, 2009).

After the milling process, the ground powders are exposed to a high pressure in a mould to produce an intensive bulk either at low temperature (referred to cold press) or as well as heating (known as hot press) (Lu and Liao, 2013).

TE materials produced by cold press method generally show lower figure of merit according to their crystalline counterparts. Cold pressing technology includes of various steps, these steps influence feature of final material discretely. Navrátil et al. observed that thermoelectric properties (electrical conductivity, Seebeck coefficient, dimensionless figure of merit) of $Sb_{2-x}Bi_xTe_3$(x=0.43-0.51) TE materials produced cold pressed varies throughout the grinding, pressing and sintering processes. A comparatively high figure of merit can be succeeded from various compositions in the existence of $Sb_{1.5}Bi_{0.5}Te_3$ alloys In related to particle size and also it is determined that the smaller grain size caused to the bigger decreasing of σ values and the Seebeck coefficient of pressed materials increased with reducing of concentration of free carriers (Navrátil et al., 1996).

Hot pressing method consists of hot pressing with mechanical alloying processes. This both processes have conduced to improvement of the TE performances (Ueno et al., 2005). Using low temperature hydrothermal method, ball milling and rapid solidification consisted hot pressing structural transitions (as known as microstructures) and based to physical effects have been succeedingly applied to bulk materials and comparatively high TE performances have been succeeded. Shen produced the polycrystalline pseudo-binary $Bi_{0.5}Sb_{1.5}Te_3$ alloys fabricated via this method. Generally as a known the Seebeck coefficient varies conversely proportional to the carrier concentration and electrical conductivity cause to two variances as the carrier concentration and mobility. Whereas the carrier

concentration is dependent on the composition, the mobility can be related to grain size, boundary, density and flaws. Circumstanly authors observed that the Seebeck coefficient values of materials reduced with temperature increase and reach a maximum value at about 300K and the differences on electrical conductivity could be caused to various carrier concentrations led to the composition (Shen et al., 2011) (Figure 2.2.).
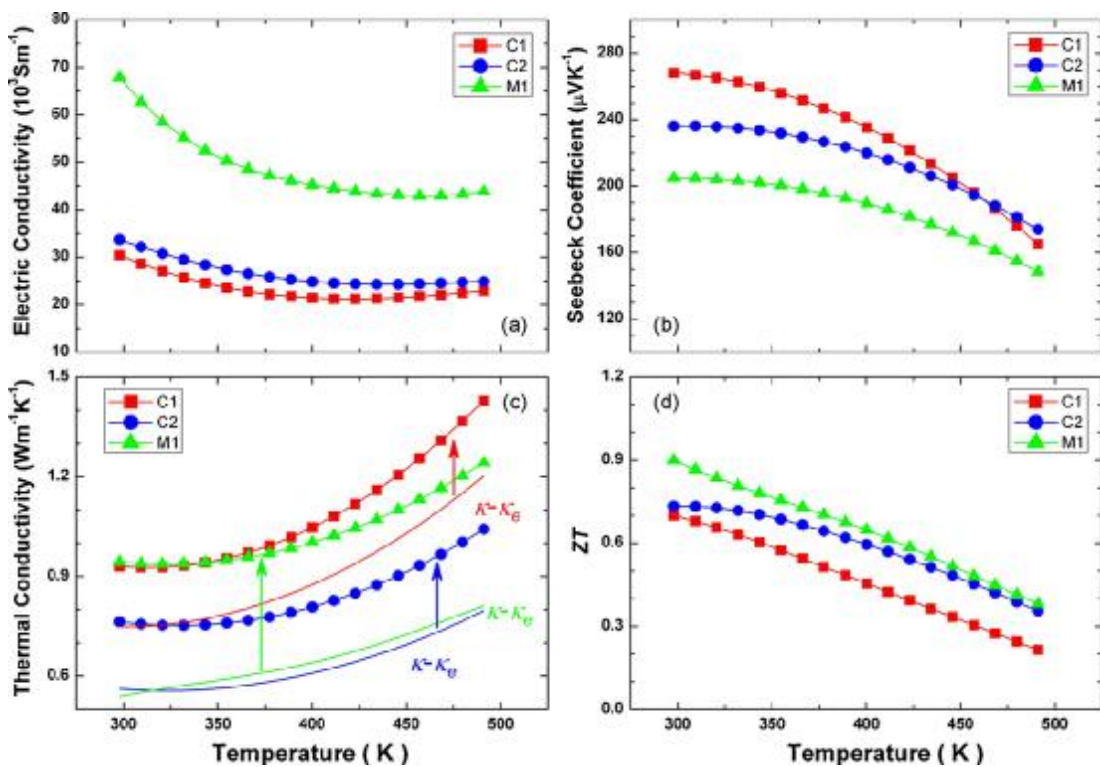
Figure 2.2. Temperature dependences of (a) the electrical conductivity,(b) the Seebeck coefficient (c) the thermal conductivity (d) ZT value. of the $Bi_{0.5}Sb_{1.5}Te_3$ bulk samples (Shen et al., 2011).

Large amount of grain boundary cause to scattering and important reduce in the conductivity because phonon conduction controls major part of thermal conductivity. MA method provides very fine grain size and hence enhances important possibility in order to enhance more efficient TE materials (Sridhar and Chattopadhyay, 1998).

For the synthesis of semiconducting TE compounds MA method is an advantageous method. The occurring powder produced by MA seems very

homogeneous and indicate low thermal conductivity because of large amount of stimulated grain boundaries. It explains the known as figure of merit. This figure of merit provides a significant measure for the performance of TE devices such as generators, Peltier coolers and sensors. (Schilz et al., 1999)

The mechanical alloying process(MA) developed by John Benjamin and his co-workers at the late 1960's is a powder processing method that enables manufacture of homogeneous materials beginning from mixed powder mixtures and is a well-established method in solid-state powder processing methods (Li et al., 2013; Suryanarayana, 2001). This method has become a well-liked method to fabricate nanocrystalline materials for various usefulness; process simplicity, the required cheap equipment, the practicability to manufacture all classes of materials. Bulk TE materials with excellent features can be prepared via mechanical alloying and the sequent consolidation of powders to enhance an ultrafine grain structure ((Li et al., 2013).

In the study of Yang et al., p-type single phase $(Bi_2 Te_3)_x (Sb_2 Te_3)_{1-x}$ (x=0.20, 0.225, 0.25, 0.275 and 0.30) thermoelectric materials with high densification prepared through bulk mechanical alloying(BMA) and hot pressing(HP) from precursor elemental Bi, Sb and Te granules with 5 N purity and 1–5 mm diameter. Authors observed for x≤0.275, rising the Seebeck coefficient with x,reachs its maximum at the composition of x= 0.275, and then reduces rapidly., the figure of merit of $(Bi_2Te_3)_x(Sb_2Te_3)_{1-x}$ reduced rapidly with increasing x, when x>0.25 (Yang et al., 2000). In the other study of Yang et al., ıt was studied n-type $(Bi_2Se_3)_x(Bi_2Te_3)_{1-x}$ with various chemical composition produced by bulk mechanical alloying(BMA) and hot pressing(HP) from precursor materials Bi, Te and Se granules. They observed the reducing the electrical resistivity and the Seebeck coefficient of $(Bi_2Se_3)_{0.05}(Bi_2Te_3)_{0.95}$ due to the doping with SbI_3, so, the enhancement of figure of merit was not materialized. To improve the thermoelectric properties, annealing the as-hot presssed $(Bi_2Se_3)_{0.05}(Bi_2Te_3)_{0.95}$ (adequately long time) acts important role and the maximum figure of merit of $(Bi_2Se_3)_{0.05}(Bi_2Te_3)_{0.95}$ was obtained as 2.31×10^{-3}/K. As a known, the thermal conductivity consists of the lattice and carrier thermal conductivity, when the doping content varies. Properly the

thermoelectric properties will be varied. In this study, the carrier concentration increases and for this reason, both the electrical and thermal conductivities rises (Yang et al., 2000) (as seen in Figure 2.3.-4.).
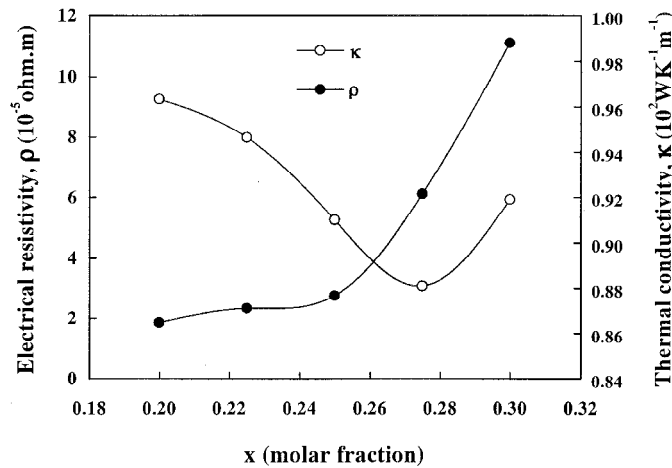
Figure 2.3. x (molar fraction) dependence of the Electrical resistivity and thermal conductivity of $(Bi_2 Te_3)_x (Sb_2 Te_3)_{1-x}$ (Yang et al., 2000).
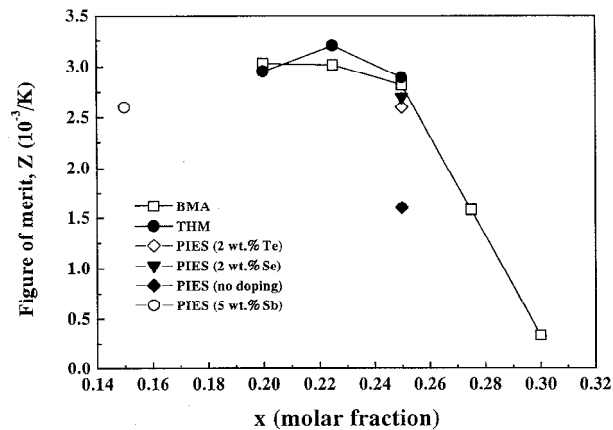
Figure. 2.4. x (molar fraction) dependence of figures of merit for $(Bi_2 Te_3)_x (Sb_2 Te_3)_{1-x}$ produced via different methods.(Yang et al., 2000).

The MG or MA technique is a very influential method in order to prepare the thermoelectric materials with high performance and more developments anticipated Katsuyama produced the thermoelectric materials via mechanical grinding (MG) or alloying (MA). The crystal grain is purified and the doped materials are distributed in the matrix through milling process. They revealed that progressed alloying between

the matrix and addition improves the phonon scattering at the grain boundaries occurring in the reduction of the thermal conductivity and however, the increasing of the Seebeck coefficient is caused to the stabilization of the matrix phase. (Katsuyama et al., 2004).

The degree of the scattering of the phonon is in proportion to the density of the below microscopic formations, and therefore, ın order to reduce of $\kappa_{ph,}$ introduce more disordered and substituted atoms, increase the density of the crystal grain boundary and more disperse the impurities, it is effective. for the low κph,the ideal microscopic structure is illustrated in Figure 2.5-6.
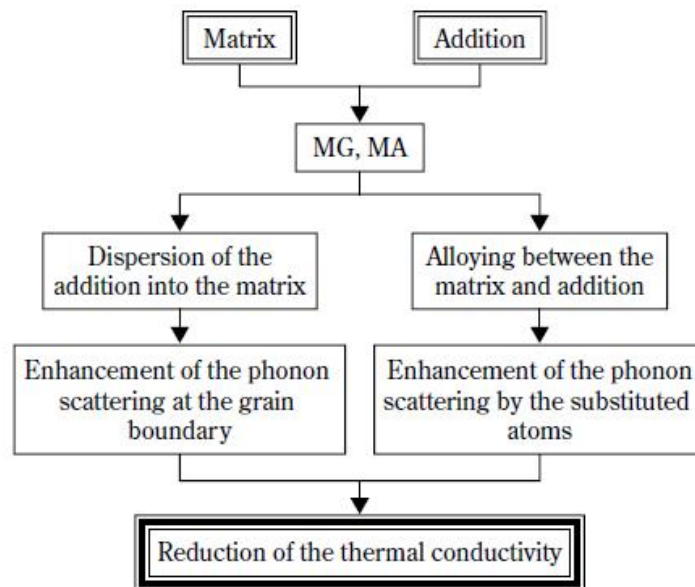
Figure. 2.5. Fundamental procedure for preparing the high performance thermoelectric materials by Powder Metallurgy (Katsuyama et al., 2004)
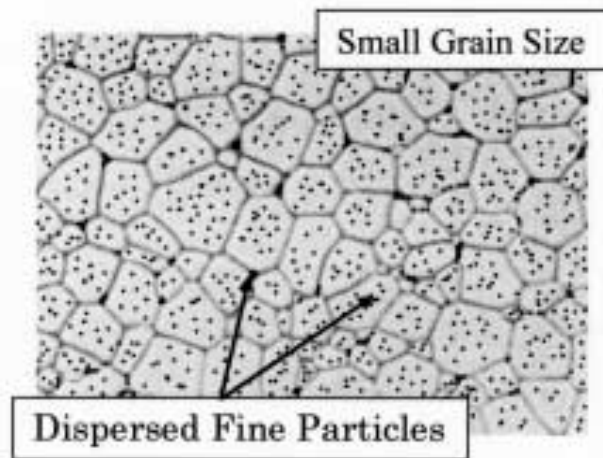
Figure. 2.6. Ideal microscopic structure for the low κ_{ph}. (Katsuyama et al., 2004).

Cryogenic grinding is a low-cost method and promises in large-scale application areas. Chen et al. produced nano-sized Bi_2Te_3 thermoelectric material powders through cryogenic grinding.

As seen in Figure 2.7., it was found that Bi_2Te_3 was not transisted into a non-equilibrium amorphous phase or decomposed through the cryogenic grinding process, and also as-prepared nano-powders possessed excellent sinterability. This technique might also be viable to the thermoelectric materials (Chen et al. 2012).
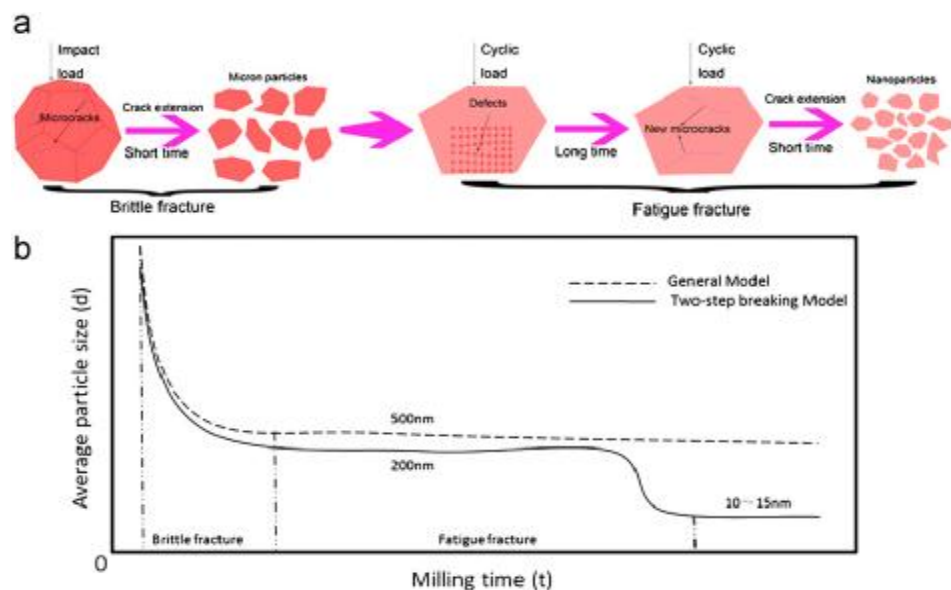
Figure 2.7. (a)A sketch of the break-down from micron to millimicron throughout the CG process. (b) Milling time related to average particle size of the CG samples as compared with that of the HEBM sample.

For characteristic powder metallurgy method, a high temperature sintering process is required to densify compacted powders and eliminate crystal flaws. This flaws resulted from ball milling and pressing processes. On the other hand, an prolonging thermal sintering process may lead to recognizable grain growth in the sintered bulk. This case is not desired for produced nanocrystalline thermoelectric materials with high ZT values (Liao, 2010).

Wang and Fan examined the thermoelectric features of $Sr_{1-x}La_xTiO_3$ nanoparticle compacts produced via the hydrothermal method followed by a cold-pressure procedure. Authors revealed the expansion of the unit cells in nanoparticles related to the improvement of thermopower and the morphology of nanoparticle compacts consisting of numerous interfaces strongly compressed the phonon thermal conductivity. It was obtained The ZT value of the nanoparticle compacts almost ~0.12 at 300 K, approximately 30% larger according to samples of both epitaxial films and single crystals (Wang and Fan, 2011) (Figure 2.8.-9.).
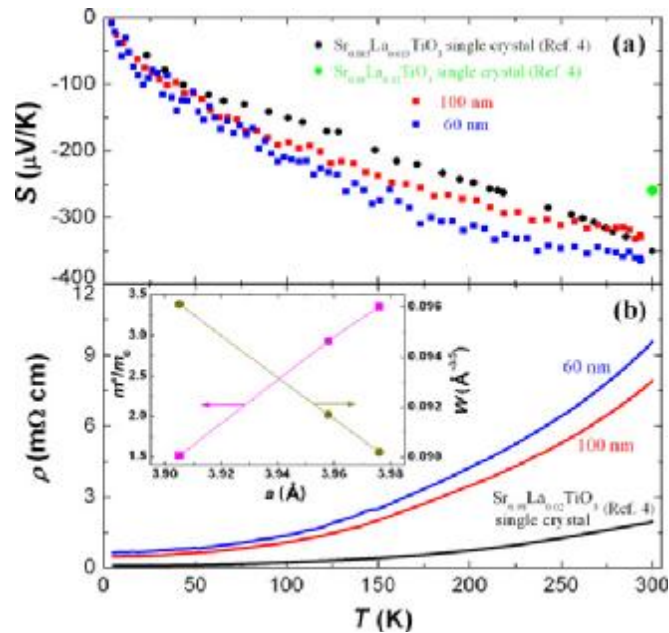
Figure 2.8. Temperature based on (a) thermopower S and (b) resistivity ρ for the nanoparticle compacts and single crystals (Wang and Fan, 2011).
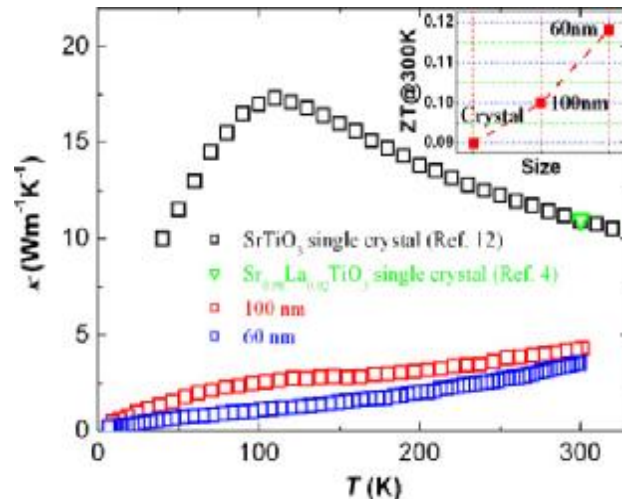
Figure 2.9. Temperature dependences of thermal conductivity κ for the nanoparticle compacts and single crystals (Wang and Fan, 2011).

Han et al., produced thermal conductive silicone rubbers filled with BN micro particles assisted with electric field assisted curing, and investigated the electric field effect and studied the thermal conductivity of BN/silicone composites with differing particle volume fractions and electric-field strengths. The electric field could happen in the constitution of an anisotropic aligned structure. The structure is put upon together the shape and thermal conductivity anisotropies of BN powder in the same direction. In this direction, the thermal conductivity has been importantly improved (Han et al, 2012).

Kuo et al. synthesized densricae fine-grained PbTe bulk materials without oxide phases prepared a process that consisted of cryomilling defined to mechanical alloying at cryogenic temperature and spark plasma sintering (SPS).ın this study, ıt was observed when the grain size decreases to the nano-scale, the thermal conductivity decreases and the Seebeck coefficient increases, the electrical conductivity only imperceptible changes for all sintered samples. They stated that the combination of cryomilling and spark plasma sintering (SPS) may enhance the thermoelectric properties of this bulk samples (Kuo et al., 2011) (Figure 2.10.).
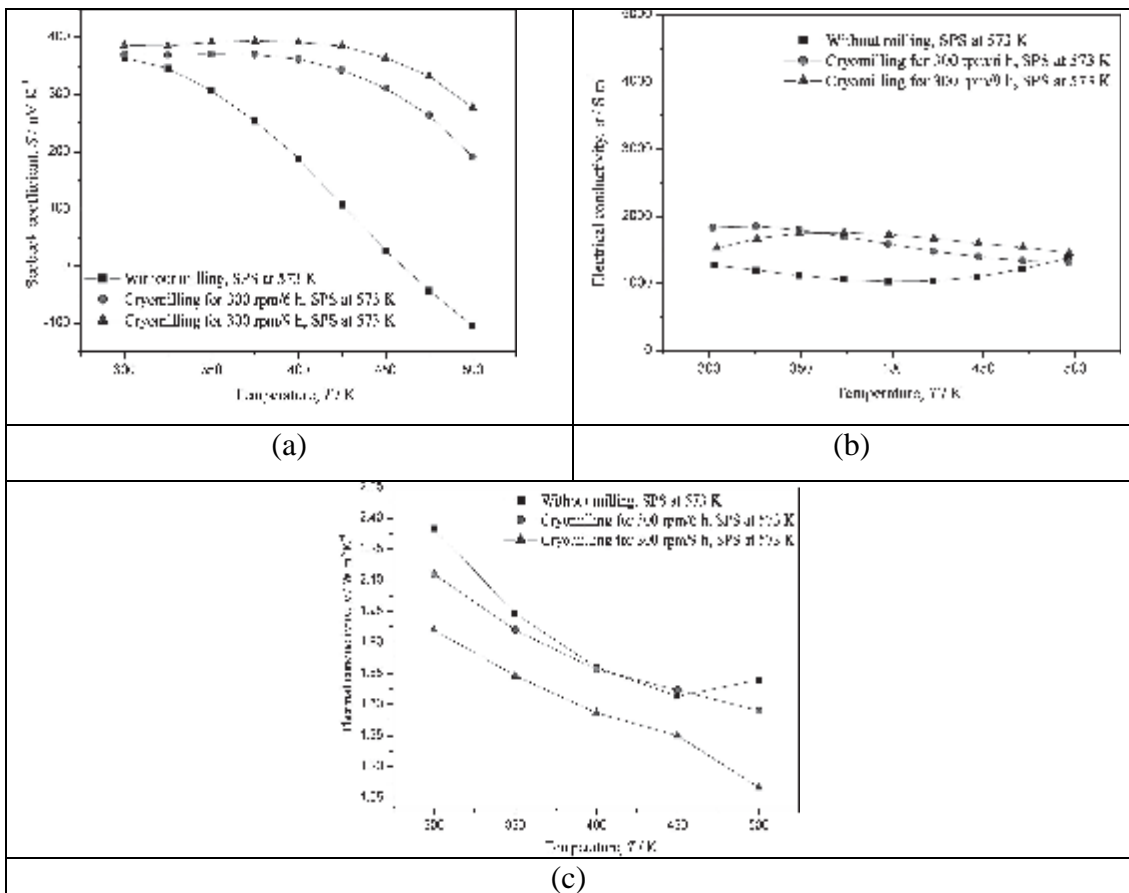
Figure. 2.10. Temperature-dependence of (a)Seebeck coefficient (b) electrical
conductivity (c) thermal conductivity for PbTe samples prepared by
different cryomilling times and sintered at 573 K (Kuo et al., 2011)

Alleno et al., prepared polycrystalline $Co_{1-x}M_XSb_3$(M=Ni, Pd) skutterudites synthesized through melting, annealing and spark plasma sintering. They determined the solubility limit of Pd and Ni of x_{max}=0.03 and x_{max}=0.09 respectively. It was anticipated the reducing values of the Seebeck coefficient with temperature for all x, in a degenerate semiconductor, till reaching the minimum increasing from the minority carrier conduction regime. It was revealed the minimum variations to higher temperature range from 540K to 630K in conformance with the rising of the electron concentration (Alleno et al., 2013).

2.2. Previous Studies on Thermoelectric Properties of Al-Zn-Mg-Cu Materials

Al-Zn-Mg-Cu alloys as-known as 7xxx series alloys are commonly used in aircraft structures, automobile industry due to their superior properties such as low density,   high strength, hardness, ductility and toughness, outstanding workability (Fang et al., 2009; Jia et al., 2012; Liu et al., 2014 ;).

The microstructure of high-strength aluminum alloys includes of three types: (i) second phase particles (constituents) (ii) dispersoids and (iii) the strengthening precipitates.

Second phase particles (constituents): The particles occur from either the existence of iron and silisium impurities or excessive amounts of major alloying elements. The final size of the particles relates to the fabrication method and the size may vary from 5 to 30 µm.

Dispersoids: The particles are known as the intermetallic particles and produced from elements such as Cr, Zr and Mn that have low solubility in Al at all temperatures. At high temperatures (350-500°C) and for long times (6-24 hrs), homogenization acts role on the precipitated dispersoid particles such as Al_3Zr and spinule grain boundaries. Therefore this case prevents grain growth throughout both thermo-mechanical processing and solution heat treatments. The size of dispersoid particles may range from 20 to 50 nm (Dixit et al., 2008).

Strengthening precipitates: The precipitation of Al-Zn-Mg-Cu alloys includes three precipitation sequences with related to the composition. The base sequence consisting mostly of Mg and Zn is considered to dominate hardening in most Al-7xxx alloys;

Supersaturated Solid Solution (SSS)$_\alpha$ $\grave{a}$ Guinier-Preston (GP) zones$\grave{a}$ spherical or disc shaped semicoherent η' , disc shaped $\grave{a}$ η

The first precipitates are coherent with the parent matrix and have metastable phase. The precipitates plays role as heterogeneous nucleation sites for more

thermodynamically stable precipitates causing to the dissolution of the metastable phases.

η-phase is a quaternary phase occurred from solid solution of $MgZn_2$ with AlCuMg components (i.e. $Mg(Zn,Al,Mg)_2$ or $Mg(Zn_2AlMg)$) and a stable phase with known as crystal structure. (Starink and Li, 2003; Waterloo et al., 2001). The Pseudo-hexagonal η'-phase is generated throughout the second aging phase. In a set of well-known direction relationships to the Al-matrix, the phase is transisted to the stable hexagonal-Laves phase η-$MgZn_2$ as larger incoherent particles (Kverneland et al., 2011).

A second one occurs generally at T> 200°C and includes the T-phase.

$$(SSS)_\alpha \to \text{GP-zones} \to \eta' \to \eta \to \text{semicoherent T'} \to T$$

If the ratio Zn: Mg is small, some aluminum will compensate for the low zinc content. T-phase particles which have the chemical composition $Mg_{32}[Al, Zn]_{49}$ will be replaced instead of η- particles. The T-phase particles consist of some copper in some alloys.

A third one includes exclusively Cu and Mg; $(SSS)\alpha \to S$.

S- phase has the Al_2CuMg (Starink and Li, 2003),(Zander and Sandröm, 2008).

Guinier-Preston zones are coherent whereas η' and η phases have semi-coherent and incoherent structures, respectively, and occur throughout quenching and aging processes (Dixit et al., 2008).

Guinier-Preston(GP)zones have two types of the GP(I) and GP(II) zones and the types are observed throughout the early stage;

Ø   **GP(I) zone:** The equiaxed zones are occurred over a wide temperature range.

Ø   **GP(II) zones:** the disc-shaped zones are one-to two layers thick on $\{111\}_{Al}$ and are occurred via aging at temperatures above 75°C (Kverneland et al., 2011)

High strength Al 7xxx series alloys are hardened via precipitation treatment process involved in solution treatment, quenching and ageing steps. Firstly; into Al-matrix, the soluble alloying elements are dissolved in solution treatment. Secondly; these elements are quenched so as to form the supersaturated solid solution. Lastly, formed solid solutions are aged artificially in order to acquire metastable η' precipitates for a certain time. As both size and distribution of these precipitates are optimized to prevent influentially the dislocations, maximum strength is reached (Zhang et al., 2014).

The metastable η' phase will maintain growing and transit to the η phase (equilibrium $MgZn_2$) throughout extended ageing. During slow cooling, the transformed equilibrium η phase can also deposit on heterogeneous nucleation structures, occur in a loss of solute from solution and a decreased strength after following ageing step (Zhang et al., 2014)

Aluminum alloys are alloyed with the elements of Zn, Mg,Cu and Zr. These elements Zn, Mg and Cu formed the Aluminum 7xxx series alloys occur precipitates of different ternary and quaternary compositions subsequent the steps of solution heat treatment and ageing. The strengthening effects of the precipitates base on their size, spacing and distribution, other mechanisms such as grain boundary strengthening, solid solution strengthening and strengthening (Dixit et al., 2008). And also the precipitation hardening relates to the process parameters such as temperatures of solution and hardening, deformation prior to the ageing, additional alloying elements (such as Cu and Zr) (Waterloo et al., 2001).

Rising of the amount of hardening elements is an influential route to strengthen the alloy (Zhao ,2013). Age hardening of Al 7xxx alloys are depend on precipitation in the Al-Zn-Mg system in the compositional range (wt%) 3-7 % zinc and 0.8-3% Mg (Kveneland et al.,2011).

By increasing the amount of zinc in the alloy, it will be acquire a higher volume fraction of secondary precipitated structures accompanied with enhanced mechanical properties. To generate dispersoids improved a secondary source of strengthening chromium, copper, zirconium are well-known materials(Sharma et al., 2008). High volume fraction of Zn content is preferred in order to enhance

mechanical features. By raising of Zn amount for the traditional casting process, the disadvantages such as coarse grains and improved macrosegregation besides crack tendency caused to the very lower cooling rate (Jia et al., 2012).

In the Al-7xxx alloy type, the complex microstructure arise from the other alloying elements like of $Al_{12}Si[Fe,Cr]_3$ and $Mg_2Si.$, the iron-rich particles are converted to Al_7Cu_2Fe structure, other subsequent heat treatment. In other words, chromium involved alloys occur $Al_{18}Cr_2Mg_3$ dispersoids. These dispersoids are concentrated in dendrite alloys. Other silicon an iron including particles which are coarse and given little contribution to the strength can also be appeared in the 7 xxx series alloys (Zander and Sanström, 2008)

2.2.1. Searching of the Electrical- Thermal Conductivities of Al7xxx Series Alloys

Guyot and Gottigines stated the investigating of the aging of AlMgZnCu alloys in a temperature range where the metastable phase η' precipitates homogeneously with a three-fold point of view utilizing the microstructural parameters and established the correlation with the electrical conductivity on the basis of a semi-phenomenological two-base model of electron scattering and the late conductivity increase ascribing to the precipitate coarsening at constant volume fraction (Guyot and Cottigines, 1996).

Salazar-Guapuriche et al. supplied a material (aluminum alloy 7010) as a plate produced from a sheet via a complex thermo-mechanical process. Authors studied the tensile strength and proof strength, hardness and electrical conductivity of Al alloy 7010 under various temper and ageing conditions, to correlate strength with hardness and electrical conductivity. They determined the acceptably linear relationship between the strength and hardness, spite of the reasonably nonlinear relationship between hardness and strength with electrical conductivity and stated the opposite effect between electrical conductivity and hardness in the natural and over ageing conditions. They also noticed the overall raising trend for both hardness and electrical conductivity, in the preternaturally aged condition owing to the constitution

of the coherent and semicoherent precipitates($MgZn_2$) and their intermediate precipitates and lattice strain hardening (Salazar- Guapuriche et al., 2006).

Feng et al., studied The effect of retrogression and re-aging(RRA) heat treatment on the microstructure and mechanical properties of a low frequency electromagnetic casting alloy as A1-9.99%Zn-1.72%Cu-2.5%Mg-O1.3%Zr. Retrogression at 200 °C for 7 min, and then re-aging at 100 °C for 24 h, the alloy acquires tensile strength up to 795 MPa, yield strength up to 767 MPa, continues 9.1% elongation, and electric conductivity of 35.6%IACS(Integrated Administration and Control System); after preaging at 100 °C for 24 h. They observed the raising the conductivity at a decreasing rate, when increasing the retrogression time, as shown in Figure. 2.11.(a). As is seen from other Figures. 2.11. (b) and (c), the effects of pre-aging and re-aging on conductivity posses the same trend, the trend is means the raising the conductivity with the extending of aging time. They revealed the most important factor impressing the conductivity firstly the retrogression time, secondly the pre-aging time and lastly re-aging time.
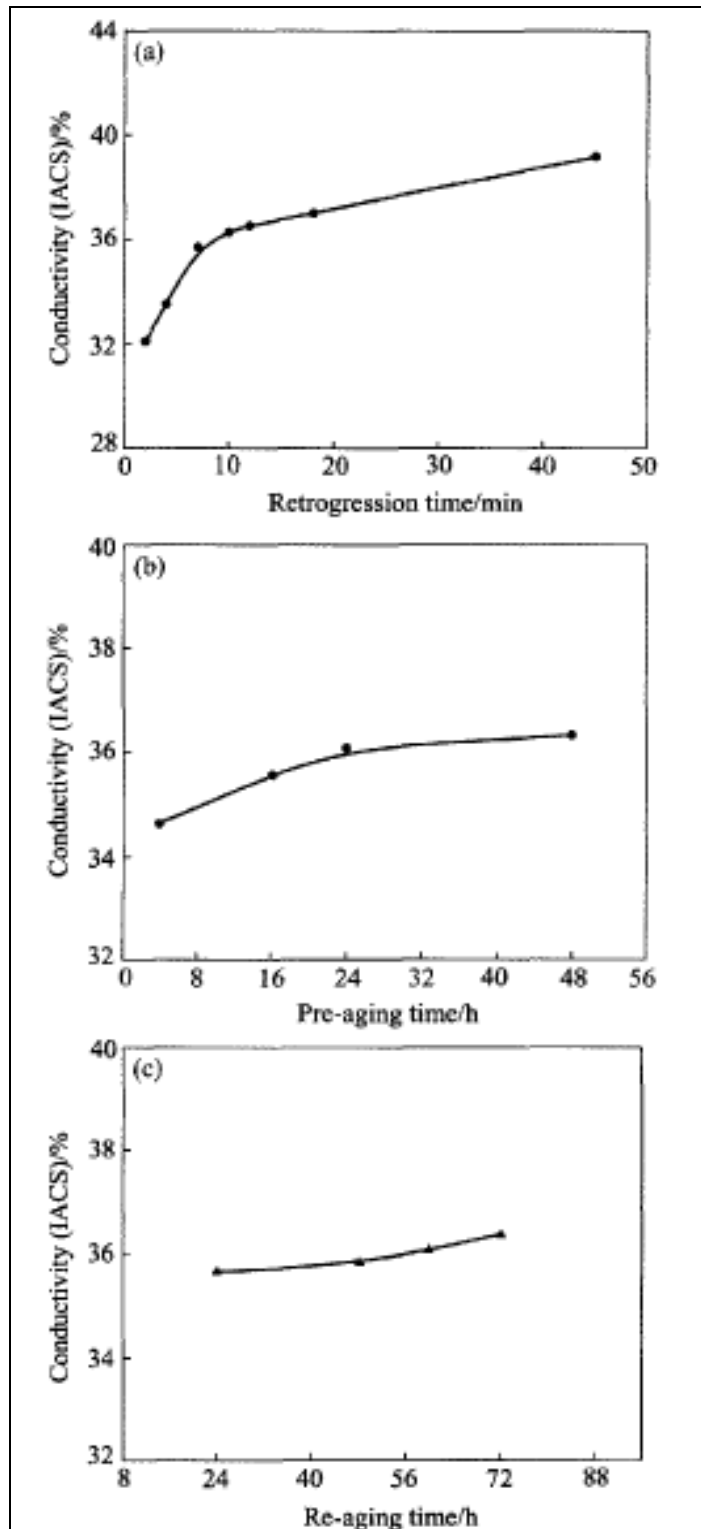
Figure 2.11. Variation of conductivity after different RRA treatments: (a) Retrogression; (b) Pre-aging; (c) Re-aging (Feng et al., 2006)

Li et al, used to 7B04 Al alloy, precipitation hardenable plate and forging material in their study. They observed the implementation of RRA treatments to material, to cause to electrical conductivities equals to T7451 condition material, simultaneously continuing the tensile strength closed to the T651 condition treated material and also showed that the retrogressed at 180° C for 60 min could generate high levels tensile properties (close to T6 strength) in integration with T74 levels electrical conductivity (Li et al.,2009).

In the article studied by Zaid et al., an implementation of retrogression and re-aging heat treatment processes are applied to improve toughness properties of the 7079-T651 aluminum alloy, while continuing the higher strength of T651-temper. It was observed the higher strength 7xxx aluminum alloys causing to low resistance to stress corrosion cracking (SCC) when aged to the peak hardness (T6 temper) and increasing the electrical conductivity with raising time or temperature of retrogression meaning the decrease of susceptibility of SCC due to the coarsening precipitates in both R-T651 and RRA-T651 alloys. (Zaid et al., 2011).

Zang et al., investigated the microstructure and the associated hardness, strength and electrical conductivity of a new Al−Zn−Mg−Cu alloy during one-step ageing treatment. Authors observed raised the electrical conductivity of the alloy continuously with raising ageing temperature and time and found the GPI and GPII zones in the alloy after ageing for 24 h at 120 °C. This case showed the existence of some stable GP zones via the ageing process. When aging at 160 °C, the hardness and strength raised rapidly after the peak value and both GPI zones and GPII zones vanished after ageing for 1 h at 160 °C.

To observe the stress corrosion cracking (SCC) resistance, The electrical conductivity is an influential method. In the Al−Zn−Mg−Cu alloy, the SCC resistance has been found to rise with increasing electrical conductivity. And the conductivity increases with increasing ageing temperature and ageing time. The electrical conductivity can be expressed as follows according to the Starink model:

$$1/\sigma_{M(t)} = \rho_{M(t)} = \rho_0 + r_{Zn} x_{Zn}(t) + r_{Mg} x_{Mg}(t) \qquad\qquad (2.1.)$$

In this above equation; $\sigma_{M(t)}$, $\rho_{M(t)}$, ρ_0 are   defined the conductivity of the matrix phase,   the resistivity of the matrix phase,   the resistivity of the alloy, respectively. $\chi_{Zn}(t)$ and $\chi_{Mg}(t)$ are referred the concentrations of the Zn and Mg elements in the matrix phase (which is time dependent, due to precipitation that can occur), after precipitation of the precipitation-hardening elements (Zn, Mg and Cu) has been completed; $r_{Zn}(t)$ and $r_{Mg}(t)$ are constant. The precipitates grow larger, so the $\chi_{Zn}(t)$ and $\chi_{Mg}(t)$ decrease, the conductivity increases with increasing ageing time, according to Eq. (1). At higher ageing temperature, the precipitates make larger more rapidly compared to at lower ageing temperature, therefore the conductivity raises sharply than at lower ageing temperature. So, the conductivity is higher at 160 °C as regards to at 120 °C at the same ageing time (Zang etal., 2012).
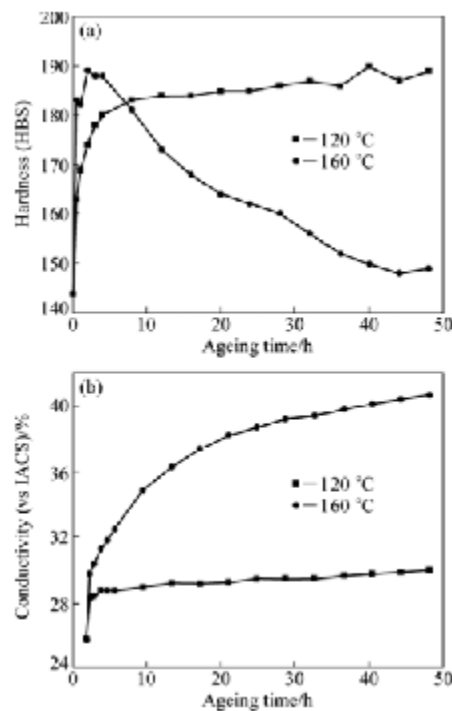
Figure 2.12. Evolution of ageing temperature on hardness (a) and conductivity (b) of
studied alloy (Zang et al., 2012).

Liu et al. studied the mechanical and electrical properties of the hot-rolled aluminum plate, with compositions (mass fractions) of Zn 7.5%, Mg 1.7%, Cu 1.4%, Zr 0.12% and Al balance.
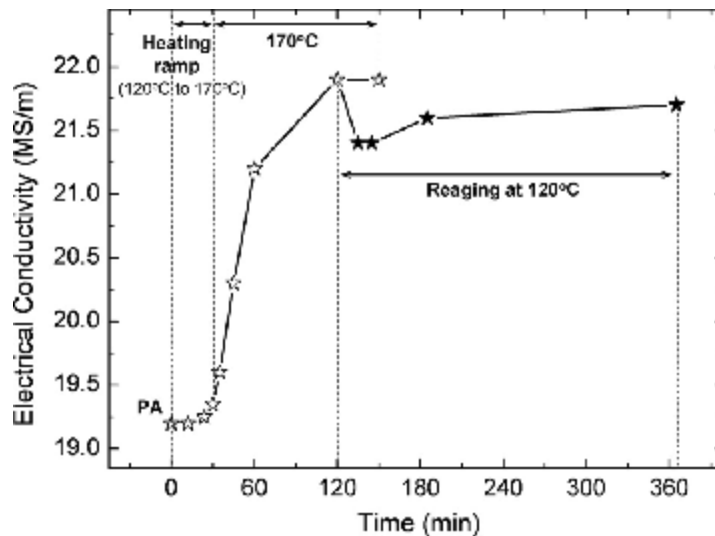
Figure 2.13. Changing variation of electrical conductivity during retrogression (open diamonds) and reaging (solid diamonds) treatments of the alloy (Liu et al., 2014).

They observed the qualified of the retrogression with a rapid dissolution stage at almost constant average precipitate size, pursued through a coarsening stage with raising precipitate size and volume fraction and a minor increase of the electrical conductivity, throughout the heating slope from 120 to 170 °C. Authors revealed the increasing electrical conductivity   with the reducing time, after retrogression at 170 °C. As a known, the electrical conductivity functionates as an indicator of SCC resistance. This indicator acts a role on the raising with increasing electrical conductivity in Al-Zn-Mg-Cu alloys.(Liu et al., 2014).

As a known, heat treatment process possesses big effect on microstructure and conductivity of the ingots, and to evaluate corrosion resistance, the conductivity is a good route. Gaosong et al. produced the ingots of high strength 7075 aluminum alloy via low frequency electromagnetic casting(LFEC) and studied the effect of various homogenization processes(single-step homogenization at 465°C for various anticipation times and three-step homogenization) on the microstructure and conductivity of 7075 aluminum alloy. Authors revealed that the grains of LFEC ingot are qualified via a lower content of low melting point phases and observed the higher electrical conductivity of the ingots compared to DC ingot under the same homogenizing conditions (Gaosong et al., 2014).

2.2.2. Searching of the Electrical Resistivity of The Al-7xxx series Alloys

Ferragut et al., studied the early stages of pre-aging at near room temperature in an Al–Zn–Mg–Cu based commercial alloy via electrical resistivity. They sufficiently defined the resistivity changes in the same terms of a Johnson–Mehl–Avrami (JMA) type function. This is required for the volume fraction growth of the Guinier–Preston zones or pre-precipitate solute clusters constituted. For one specific case, authors specified the resistivity results with those acquired throughout synchrotron-radiation small-angle X-ray scattering (SR-SAXS).
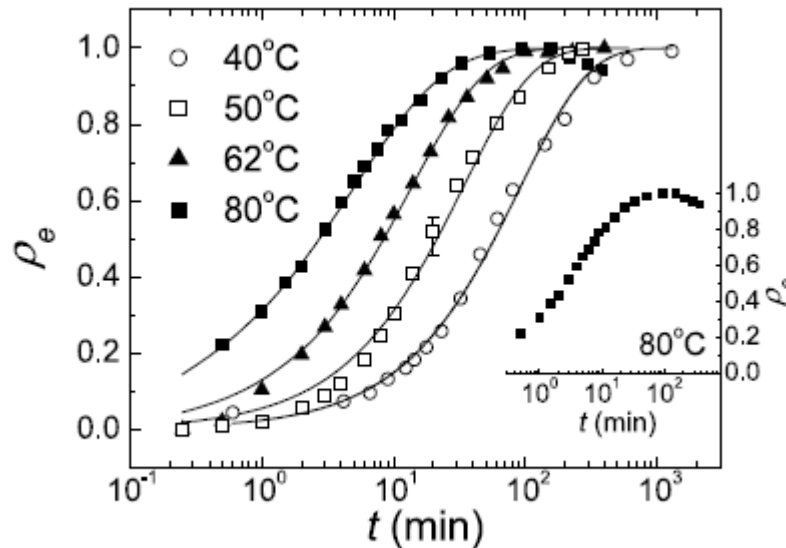
Figure 2.14. Isothermal pre-aging curves of the relative resistivity ρ_e at various temperatures for samples of 7012 alloy quenched at 470 °C.

Authors thermally treated the samples were thermally treated via : (i) in an electric air circulating furnace and water quenching at 20 °C, homogenization process for 2 h at 470 °C; (ii) pre-aging at various temperatures: 40, 50, 62 and 80 °C for various aging times (see Figure 2.14.).

As seen in The Figure 2.34,   it is appeared that the evolution of the relative resistivity ρ_e acts as a function of the pre-aging time t at different temperatures. To prevent the nucleation of incoherent particles, authors selected the temperatures of

the pre-aging heat treatments of low enough at near room temperature. The relative resistivity is expressed as follows:

$$\rho_e = \frac{\rho(t) - \rho_i}{\rho_s - \rho_i}$$

(2.2.)

Where, ρ_i is defined the initial resistivity value after quenching, ρ_s is the maximum resistivity value and $\rho(t)$ is the measured instantaneous resistivity value.

In below equation, the relative resistivity ρ_e increase could be well stated by means of a Johnson–Mehl– Avrami(JMA) function, in the limit case of small pre-precipitates, throughout pre-aging.

$$\rho_e = 1 - \exp\left[-\left(\frac{t}{t_C}\right)^n \right]$$

(2.3.)

Where, the parameters t_C and n, base on the diffusion conditions and related to the change of the relative resistivity at each pre-aging temperature. Acquired n values are in suitable agreement with those procured for some Al–Zn–Mg alloys (with both high Zn and low variable Mg contents) owing to resistivity measurements under similar thermal treatments, i.e. aging at near RT after quenching. They also stated that the resistivity changes would be depended on the volume fraction growth of the generated pre-precipitate particles such as GP zones or precipitate solute clusters) (Ferragut et al., 2002; Ferragut et al, 1999).

The base precipitating phase (defined M) in 7xxx alloys is isomorphous phase to $MgZn_2$, while other phases can also nucleate on quenching(S and T phases). Grain boundary and subgrain boundaries formed at lower temperatures plays role as intergranular nucleation sites despite chromium or zirconium acting as intragranular sites. In studies, qualifying the precipitation processes in aluminum alloys it benefits from resistivity measurements. Archambault and Godard investigated the electrical resistivity of an industrial 100 mm thick plate AA7010 cast and rolled via Pechinery

Rhenalu Issorie. In their study, they developed a very sensitivity measurement method to specify the high temperature precipitation kinetics in aluminum alloys. They observed the different precipitation processes appeared throughout DSC above 200°C finding out as a single process via the resistivity measurement. This measurement supports the validity of the Mathiessen's rule in this temperature range. the resistivity variation , showed firstly a sharp reduce because of the 50°C/s cooling before holding in order to interrupt quenching and isothermal holding conditions, (Figure 2.15.). Then, it was observed the smoother and pursued through an asymptotic plateau. They discerned the raising of the resistivity variation with the reducing holding temperature.
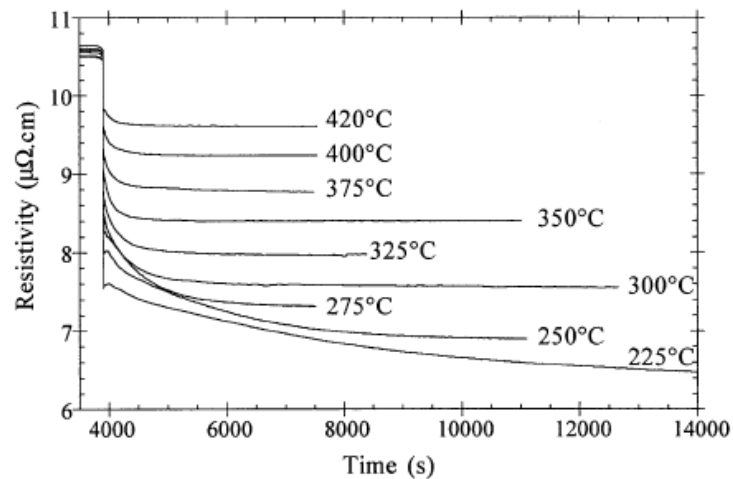
Figure 2.15. Changing of the resistivity throughout isothermal holdings then interrupted   quenching   from   the   solutionizing   temperature (Archambault and Godard, 2000).

The magnitude of the precipitation relates to the decomposition temperature and on the cooling rate. They specified   the precipitation kinetics for the three linear cooling rates between 475 and 200°C and acquired the similar kinetics via two techniques for the 10°C/mn cooling rate (see figure 3) and observed the pursuing the resistivity to the Matthiessen's rule over this temperature range and following the differential resistivity to the decomposition of the solid solution (Archambault and Godard, 2000).
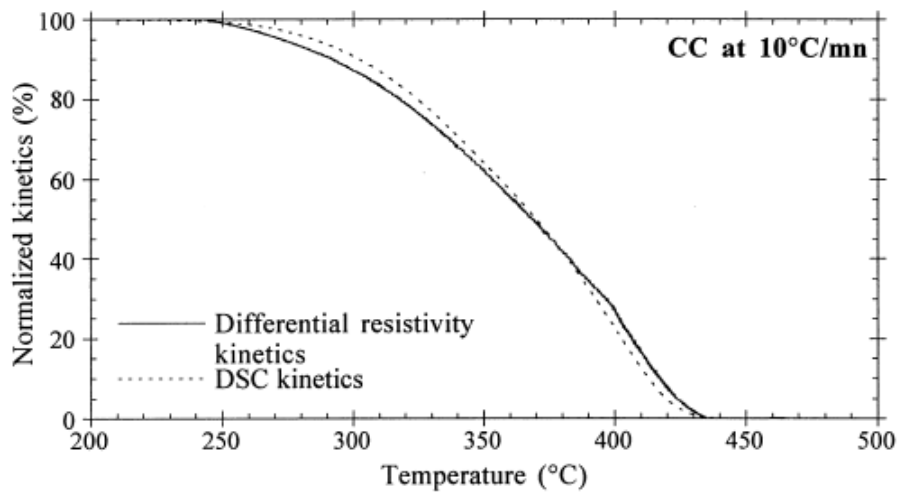
Figure 2.16. Temperature based on precipitation kinetics obtained between 475 and 200°C by DSC and resistivity measurement for the 10°C/mn cooling (Archambault and Godard, 2000).

Dellah et al. investigated the structural, electrical resistivity and hardness changes of aged Al– Zn–Mg alloys.   They showed that the isothermal annealing in temperature range of 25–200 °C causes to the sequent   precipitation sequence: Guinier–Preston zones à η'-phase à η-phase; and revealed the important increase of electrical resistivity (ρ) of the considered alloys relating to the stage of GP zone decomposition. It was observed that the constitution of the intermediate η'-phase was accompanied with both a decrease of electrical resistivity and an increase of hardness and found the Non-continuous quenching to suppress the η'-phase formation; spite of causing the elevated quenching rates to the formation of uniformly scattered fine precipitates in the alloy bulk (Dellah et al., 2013).

In the previous studies, It was studied the Figure of Merit and Seebeck Coefficient of Al-7xxx Series alloys, In this work, ıt has been searched the thermoelectric properties such as Seebeck coefficient, figure of merit accompanied with Electrical resistivity, Thermal conductivity of Alumix 431 alloy which is the Al 7xxx series alloy.

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3. MATERIAL AND METHOD

3.1. Material

In this thesis work, the material used was Alumix 431® powder which is a mixture of Al 7xxx series aluminum alloy and obtained from Ecka Granules in Germany. The chemical composition and particle size characteristics of Alumix 431 powders utilized in this work is given in table 3.1.

Table 3.1. Typical chemical composition and physical characteristics of Alumix 431 Material

Chemical Composition,% (density 2.786 g/cm^{-3})		Particle Size Distribution (µm)	
Al	89	D_{10}	54.8
Cu	1.5	D_{50}	107.2
Mg	2.5	D_{90}	193.1
Zn	5.5	*S_w	4.7
Lubricant	1.5	Mean Value	18.2

*S_w means the particle size distribution slope.

As seen in table 3.1., the Alumix 431 series alloy is based on additions of zinc, magnesium and copper and the material is a high strength alloy. Zinc is dissoluble in aluminum, important alloying addition for Alumix 431 and supports to the precipitation hardening (Ekşi et al., 2004). A practical limit of about 8wt% Zn is implemented for traditional cast materials due to intrinsic foundry problems like solute macrosegregation and cracking (Feng et al., 2009). Copper is doped to these alloys to enhance the wetting behavior of the liquid phase of aluminum and also supports to precipitation hardening as Zinc element (Ekşi et al., 2004). Both copper containing and zinc containing aluminum alloys possess a high strength/weight ratio and have been extensively implemented in aerospace, automotive, textile engineering etc. Really, zinc effect on the strength of aluminum alloy is more important compared to effect of copper. The Al-7xxx alloys are sensitive to localize corrosion

because of the existence of strengthening phases such as $MgZn_2$, $AlMg_3Zn_2$, Al_3CuMg (Xue et al., 2007). Mg is the lightest material and indicates superior properties such as high dimensional stability and thermal conductivity, good formability and recyclability. Spite of its advantages, there is a major disadvantage of Mg element as inadequate corrosion resistance because of high reactivity. Mg and its alloys are also qualified via low hardness and wear resistance, so their useful areas are restricted to mechanical parts working under static conditions such as casing, housing (Mola , 2013). Magnesium even at 0.5% level, have positive effect on shrinkage via decreasing the oxide, permitting metal/metal contact at particle interfaces and facilitating diffusion (Ekşi et al., 2004).

3.2. Method

3.2.1. Manufacturation Method of Specimens

In this thesis work, the specimens used, were previously prepared. First of all, the components of powder (Al-5.5 Zn-2.5 Mg-1.5 Cu; elemental mixing is in weight%.) which are approximately weight of 15 g are mixed to put into blanks , together with lubricant, until a homogeneous mix is obtained using a 3-D Turbula Mixer.The specimens were compacted in a cylindrical mold of 15 mm diameter to obtain compacts of about height of 15 mm which has almost 3.5 g in weight with an accuracy of 0.001 g for static features. They were pressed up between 300 and 500 MPa pressure and specimens was applied at two various temperatures and pressing conditions; room temperature (RT), 50°C and 80°C. Warm compaction was implemented through a furnace of Heraeus, UT 12P.
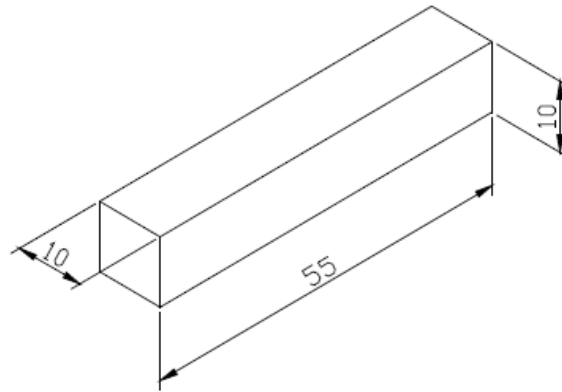
Figure 3.1. Compacted aluminium alloy used in this study.

In order to investigate the thermoelectric properties , the samples cracked so as to replace properly to probe-holder of machine as shown in Figure 3.2.

Figure 3.2. The cracked samples for measuring thermoelectric properties

3.2.2. Characterization Methods of Alumix 431 Specimens

3.2.2.1. Optical Microscope and Scanning Electron Microscope (SEM) Characterization Methods

In both optical and Scanning Electron Microscope (SEM), preparation of sample is important. Firstly, the specimens are cut and grinded to size and polished the surface to subject to the features. These steps are widely defined as metallography.
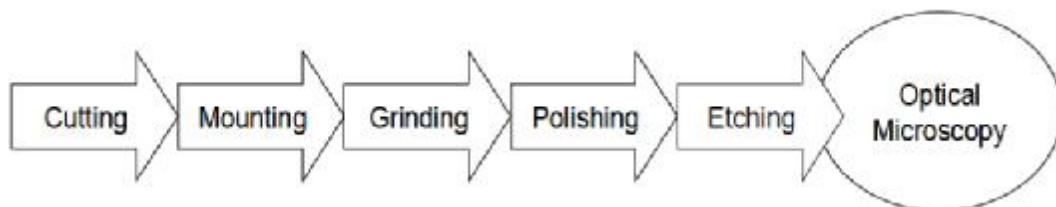
Figure 3.3. Specimen preparation steps for Optical Microscopy and SEM (Dilek, 2006)

In optical microscopy, the probing beam is light; this is reflected off or conveyed via sample before the image of specimen occurs. The image is generated by opposed among various properties of sample. This features such as brightness, phase, colour, polarization, fluorescence base on the illuminating source. Magnification is checked via a system of optical lenses. Resolution restriction is normally lined off throughout the light wavelength or maximum magnification value will be enhanced any significant contrast.

In Scanning Electron Microscope (SEM), the observing of electrically insulating material occurs via electrically isolated sample' surface, when bombarding with electrons. This case causes to a charge build-up on the samples, this makes either imaging or other analysis hard.

The morphology and microscope examinations of pressed samples have been done by light (Leica DMRX) and scanning electron microscopy (LEO 1530 GEMINI).

3.2.2.2. Density Measurements of Alumix 431 Specimens

Density of samples were measured by Classical Method and the Archimeds Principle (water displacement technique) using Presica 320XT series for analytical and precision balances which has 1/10000precision of scale in Gazi University's Mechanical Research Laboratory in Ankara, Turkey. Archimedes Principle is simple to implement, experiemental results can be reckoned rapidly., Precisa Density Measurement Set is also used , so as to measure densities by Archimedes Principle. This set specially produced with this balance includes of liquid tube carrier table, specimen holder, glass liquid tube and fitted temperature for liquid. Pure water is used for measuring media at room temperature, 22 ℃ for this study.

According to Classical Method and Archimedes Principle, there are a lot of the basic formulas related to density. These are given with symbols and explanations to determine densities of samples below:

 a) Classical Method to determine the green density

ρ_{green} = Green density of specimen, g / cm^3

m_{green}= Green mass of specimen, g

v_{green} = Green volume of specimen, cm^3

$$\rho_{green} = m_{geren} / v_{green}$$ (3.1.)

b) Archimedes Method to determine the sintered density

x = Weight of specimen, g

y = Carrier material weight, g

z = Weight of specimen in the water, g

b = Difference of weight, g

a = Weight without carrier bond, g

ρsintered = Sintered density of specimen, g / cm 3

k = 0, 9999 (special constant for pure water at 18-26 °C temperature from handbook of the density measurement set)

a = z – y   (3.2.

b = x – a   (3.3)

$\rho_{sintered}$ = k.x/b   (3.4)

The densities have been calculated easily with the help of these equations to compare used all data in connecting with density in this work.

3.2.2.3. Measurement of Thermal Transport Properties Of Alumix 431 Specimens Via The Physical Properties Measurement Systems (PPMS)

For physical features such as heat capacity, magnetization, magnetic torque, Hall effect, DC-resistivity and other thermal and electronic properties of a specimen, the PPMS produced by Quantum Design, is various temperature field systems. The system permits automated measurements. The magnetic field can be installed to 9 T and the temperature interval ranges from 1.8 to 400 K or down to 0.4 K with a Helium 3 refrigerator(Figure 3.5-13).

Figure 3.5. The PPMS of Model 6000 PPMS Machine.

Figure 3.6. The Model 6000 Controller of Model 6000 PPMS Machine.

Figure 3.7. The NMR Apparatus and PPMS head of Model 6000 PPMS machine.
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Figure 3.8. Samples prepared to examine the thermal-transport properties.
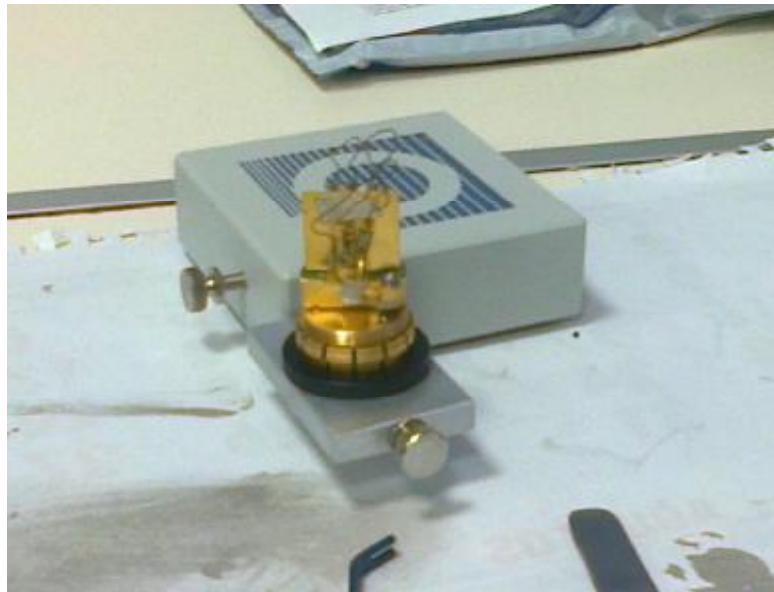
Figure 3.9. Sample-holder of PPMS machine.
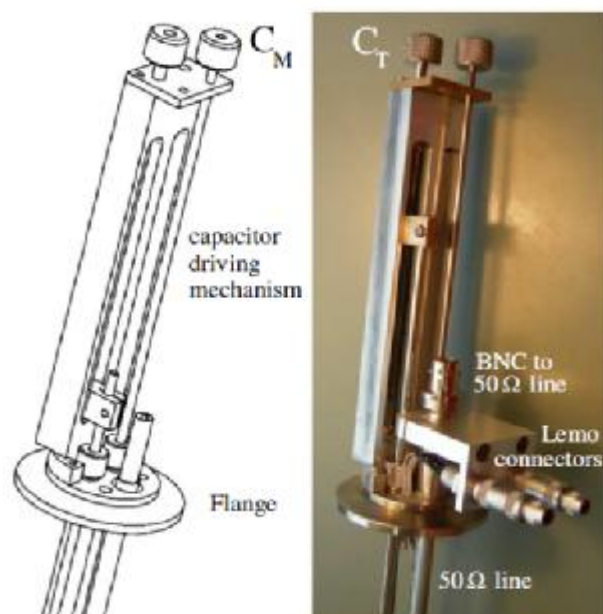
Figure 3.10 . The upper part of the NMR probe head (Gafner, 2006).
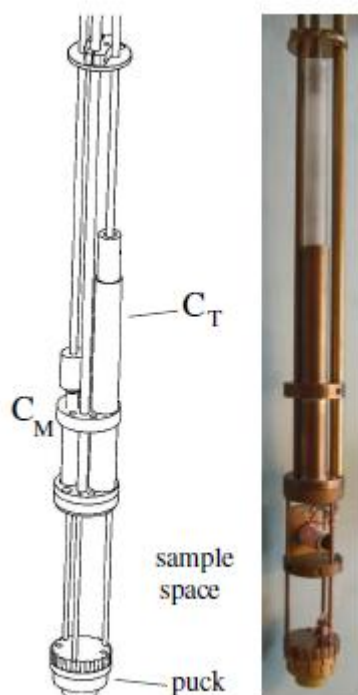
Figure 3.11. The bottom part of NMR probe head (Gafner, 2006).

Figure 3.12. The NMR probe head (Gafner, 2006).
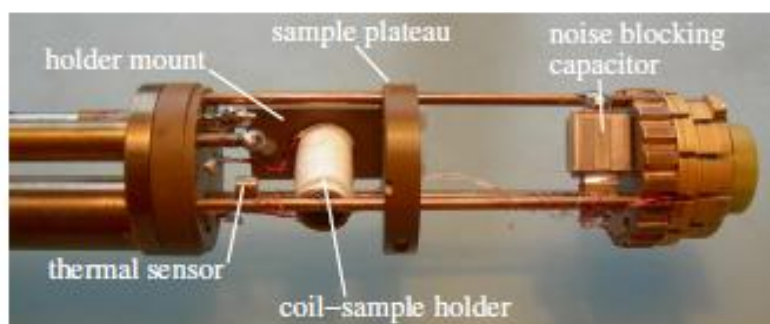
Figure 3.13. The sample holder, plateau, thermal sensor and noise-blocking capacitor
(Gafner, 2006).

The system can be exactly checked and displayed via either the model 6000 controller or MultiVu software running on PC. Simple sequence scriptcan be written with MultiVu software, so as to allow the PPMS work fully automatized.

The high capacity nitrogen jacked thermos hampers fast liquid helium evaporation loss. The PPMS interpolate with the superconducting magnet is submerged in liquid helium. The outer layer of the insert is a superconducting magnet. The magnet is made of NbTi / Nb_3Sn. In order to adjust the magnetic , there are three modes; the oscillating mode, the no-overshooting mode and the linear mode. The no-overshooting and the linear modes culminate in a field drift whereas

the oscillating mode is almost stable. The uniformity of field is insisted to ±0.01% over a (5.5×1) cm cylindrical volume with the center at 5.1 cm above the puck surface.

In order to check the temperature of PPMS proposes the high temperature control and the continuous low-temperature control techniques. These permit a fast cooling and heating of the PPMS specimen surface, a smooth transition through the 4.2K helium boiling point and continue mistily a temperature below 4.2 K (Gafner, 2006).

For the Physical Property Measurement System (PPMS), the Quantum Design Thermal Transport option (TTO) allow measurements of thermal properties, such as thermal conductivity κ and Seebeck coefficient (also called the thermopower) α, for sample materials over the entire temperature and magnetic field range of the PPMS. In the measurement of thermal conductivity, the TTO system is occurred via by monitoring the temperature drop along the sample as a known amount of heat passes through the sample and in the measurement of thermoelectric Seebeck effect, the system is carried out as an electrical voltage drop that come along a temperature drop across certain materials. These two measurements are implemented concurrently throughout monitoring both the temperature and voltage drop across a sample as a heat pulse is performed to one end, via The TTO system. The system can also measure electrical resistivity ρ throughout the standard four-probe resistivity enhanced via the PPMS. AC Transport Measurement System (ACT) option (Model P600). In order to specify the so-called "thermoelectric figure of merit," $ZT = \alpha^2 T/\kappa\rho$, all three measurement types are important. The figure of merit is usually stated as the dimensionless quantity $Z \times T$, where $Z \times T \sim 1$ is a common consideration for viability of a material for thermoelectric applications.

Table 3.2. System Requirements for the Thermal Transport System

Component	Function
PPMS Resistivity Option (Model P400)	Enhancing user bridge board that reads two thermometer shoes.
PPMS AC Transport Measurement System (Model P600)	Outputs current to heater and sample while providing low-noise, phase-sensitive detection
PPMS High-Vacuum Option (Model P640)	Provides thermal isolation for measurements. Cryopump or Turbo Pump may be used
PPMS MultiVu Software Version 1.1.6 or Later	Provides single user interface for PPMS and PPMS options.

Table 3.3. Thermal Transport System Parameters

Parameter	Value
Pressure	High vacuum ($\sim 10^{-4}$ torr)
Temperature	$1.9-390$ K
Magnetic field	$0-14$ T when T > 20 K

Measurement Modes: The TTO system involve two measurement modes; (i) continuous measurement mode and (ii) single measurement mode. Measurements of all properties proposed via TTO can be applied in either of these two modes.

In continuous measurement mode, to optimize the measurements, measurements are being taken progressively and the adaptive software is setting parameters (such as heater power and period). This mode is depended on slow sweepings of system variables such as temperature or magnetic field, and it is often the most rapid way of obtaining. via the use of a complicated curve-fitting algorithm the continuous mode is also speed up.The algorithm specifies the steady-state thermal properties throughout estimating from the response to a relatively short (typically several minutes) heat pulse.

In the single measurement mode, mode is operated slower than continuous measurement mode because of   its requirement that reached of the system to   a steady state in both the heater "off" and "on" states, The advantage of single measurement mode is necessity of no subtle curve-fitting calculations ,   therefore remark of the raw data is more obvious..

Measurement of Thermal Properties: The TTO system is adjusted to measure four thermal transport properties:

- Thermal conductivity
- Seebeck coefficient
- Electrical resistivity
- Thermoelectric figure of merit

The thermoelectric figure of merit, which is the algebraic combination of these three measurements, can be calculated ,when thermal conductivity, Seebeck coefficient, and electrical resistivity are all measured.

Thermal Conductivity: The TTO system measures thermal conductivity κ via implementing heat from the heater shoe so as to occur a user-determined temperature differential between the two thermometer shoes. In terms of the thermal response of the sample to the low-frequency, square-wave heat pulse,The TTO system dynamically is been model, thus speeding up data acquisition and TTO system can be reckoned thermal conductivity directly from the implemented heater power, occuring ΔT, and sample geometry.

Seebeck Coefficient: the Seebeck coefficient (also called the thermopower) α specified The TTO system via occuring a determined temperature drop between the two thermometer shoes.   However, the voltage drop created between the thermometer shoes is also monitored for Seebeck coefficient measurement. these thermometer shoes caused to the additional voltage –sense are connected to the ultra-low-noise preamplifier of the ACT system.

Electrical Resistivity: The TTO system measures electrical resistivity ρ via using both a precision DSP current source and phase-sensitive voltage detection. For

this AC resistivity measurement, the specifications are importantly identical to those for the AC Transport Measurement System (ACT) option.

Figure of Merit: The dimensionless thermoelectric figure of merit ZT is determined here simply as the algebraic combination $ZT = \alpha^2 T/\kappa\rho$ of the three measured quantities−thermal conductivity.

In this thesis work, Model 6000 Physical Property Measurement System , Quantum Design machine was utilized to measure the thermal transport properties such as electrical resistivity, thermal conductivity, Seebeck coefficient and figure of merit. Specimens measured in this machine were cut so as to replace properly to probe-holder of machine.

4. RESULTS AND DISCUSSIONS

In this study, the thermoelectric properties of alumix (431) (Al-5.5 Zn-2.5Mg-1.5Cu) prepared on different pressures and temperatures have been investigated. It was examined Optical microscope, SEM images and density measurements of specimens for their structural properties and searched the electrical resistivity, thermal conductivity, Seebeck coefficient, the dimensionless figure of merit (ZT) data obtained from PPMS Quantum Design (Physical Property Measurement System) at measured temperature ranges 5-300 K for their thermoelectric properties.

In this study, the samples prepared on different pressures and temperatures were symbolized 1, 2, 3, 4, 5, 6

Alumix 1	350MPa, RT
Alumix 2	350MPa, 50°C
Alumix 3	350 MPa, 80°C
Alumix 4	400MPa, RT
Alumix 5	400MPA, 50°C
Alumix 6	400MPa, 80°C

4.1. Analysis of Optical Micrographic Figures of Alumix (431) 1, 2, 3, 4, 5 ,6 Specimens

In Figures 4.1, and 4.2, the badge microstructure of primary α-Al solid solution turned round via inter-dendritic secondary phases and some grain boundary precipitates having laminar morphology was shown. It was observed that the microstructures have the eutectic characteristic structure. In the microstructure, it is considered the existence of the coarse eutectic phases relating of the high amount of Zn, Mg and Cu in the alloys and low cooling rate linking to the traditional solidification process.

Figures 4.1 and 4.2 show the microstructure of Al-5.5Zn-2.5 Mg-1.5Cu alloy comprised of the both equiaxed grains and some fine secondary phases. The existence of the equiaxed grain morphology is considered to result from the high cooling rate, related to the rapid solidification processes. On the contrary, the existence of coarse eutectic phases in the IM counterpart processed traditionally was repressed.

In this Figures 4.1 and 4.2, it is also shown that second phases having both the grain boundaries and in the grain inners. The second phases in the grain inners reveal different shapes such as needle and square microstructure shape of particles. Along the matrix, most of the second phases is the comparative uniformly dispersed and it is sighted the some of the grain boundary precipitates possessing an allotriomorphic morphology (Feng et al. 2009)

The concentrated second phases have eutectic precipitated from the liquid phase directly at grain boundary. The distributed gray phases within the grains are mostly the strengthening phase ($MgZn_2$). The phase is precipitated from solid based body. In the microstructure, it was observed the some tiny pores. The pores decrease by the mechanical properties.

Figure 4.1. Optical microscope image of alumix (431) sample (50µm).

Figure 4.2. Optical microscope image of alumix (431) sample (20µm).

The cracks near the crack source zone of the fracture are intergranular microstructure. Course of events of deep into certain depth, the cracks transits into transcrystalline. Some coarse particles were sighted on the surface of the specimens. This case manifests the fatigue damage (see in Figure 4.3.) (Hai-Gen et al., 2009).

Figure 4.3. Optical microscope image of alumix (431) sample with transactions (10µm).

In the figure 4.4., ıt is observed that an equiaxed grains and two types of phases with apparent origins. The first one is the phase occurred at the grain boundaries throughout the solidification process led by the segregation of the alloying elements. The other phase is commonly constituted near the grain boundary. This case resulted from coring leading precipitation. Many coarse precipitates are apparent within the constituted grains (Mazzer et al. 2013).
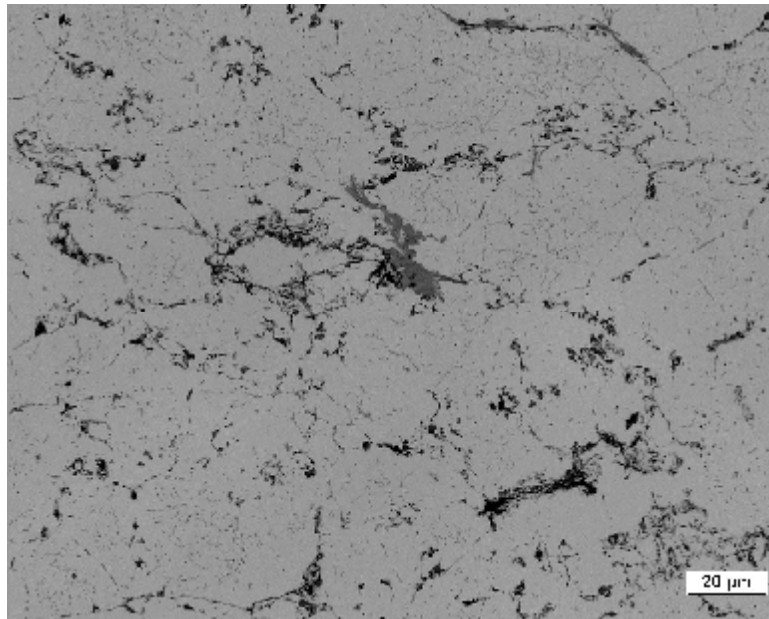

Figure 4.4. Optical microscope image of alumix (431) sample with materials (20µm).

4.2. Analysis of SEM Figures of Alumix (431) 1, 2, 3, 4, 5, 6 Specimens

Figures 4.5-8 present the fracture surface of the samples. Many fine holes specified ductile resulted from fracture can be observed. Holes caused from the aged sample treated smaller than the solution heat treatment. It manifests the precipitated particles have affected the fracture occurred. At the grain and subgrain boundaries, the smaller holes are constituted because of the existence of the equilibrium η ph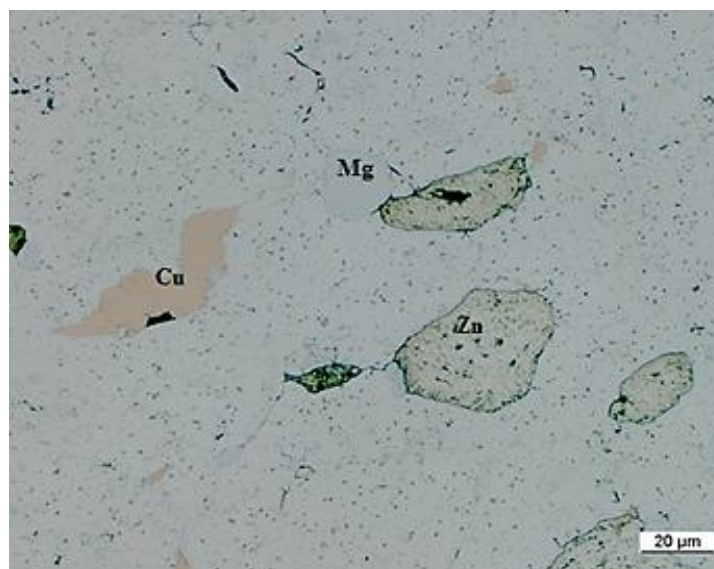ase at these regions. This phase decrease the plastic deformation at the zone and the following plastic flow around the precipitates (Mazzer et al. 2013).

The precipitation behavior in α-Al matrix is related to the mechanical properties sized such as the ductility change and strength of various hot deformation treatments linked to size, dispersion and volume fraction of the precipitated second phases. It is observed the transgranular microstructures and fine holes with secondary cracks, in the figures. This case means the undissolved coarse phases caused to stress concentration. This stress concentration occurs in the constitution of the secondary cracks in the matrix and worsening influence on the ductility (Jia et al. 2012).

Deep and fewer holes were observed. The holes caused from including of secondary phases. It is considered the fracture of precipitates induced to the fracture. Naturally aged joints showed the fracture surface surrounded with deeper and larger holes besides few flat zones. Some deep hollows can be observed on the surface of the fracture (Figures 4.5-8) (Sharma et al. 2013).

The surface of fractures showed the mainly cup-cone holes with changing and no such intergranular cracks are seen. This case is explained the ductile fracture, non-similar intergranular brittle failure (Rout et al. 2014).
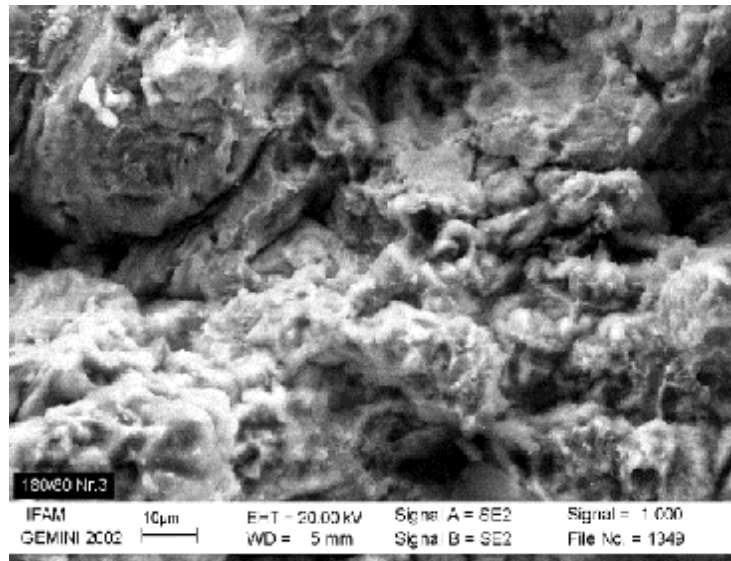
Figure 4.5. SEM image of Alumix (431) sample prepared under the 180MPa and 80°
conditions(10µm).

Figure 4.6. SEM image of Alumix (431) sample prepared under the 180MPa and 80°
C conditions (20µm).

4.3. Density Measurements of Alumix 431 Specimens

The results of the density measurements of Alumix 431 indicates the highest density on compacted specimen at 400MPa/RT. It was observed the decreasing porosity and homogeneous structure with increasing temperature. This case is shown that the density was influenced directly with decreasing porosity and shrinkage of pores was generated because of reducing of volume of sintered parts and non-varied weight. Therefore, these conditions increased the density. High density is resulted from high strength of sintered parts and high density also influences mechanical properties such as strength, toughness and hardness. For this reason, high density property is a desirable feature (İynen et al., 2010)(Figure 3.1-2).

Figure 4.7. The green density (g/cm^3) changes of Alumix 431 samples related to compression pressure(MPa)(İynen,2009).

Figure 4.8. Relationship between the compaction pressure and green strength of the samples prepared in three various compaction temperatures (İynen,2009).

4.4. Analysis of Electrical Resistivity Results of Alumix (431) 1, 2, 3, 4, 5, 6 Specimens
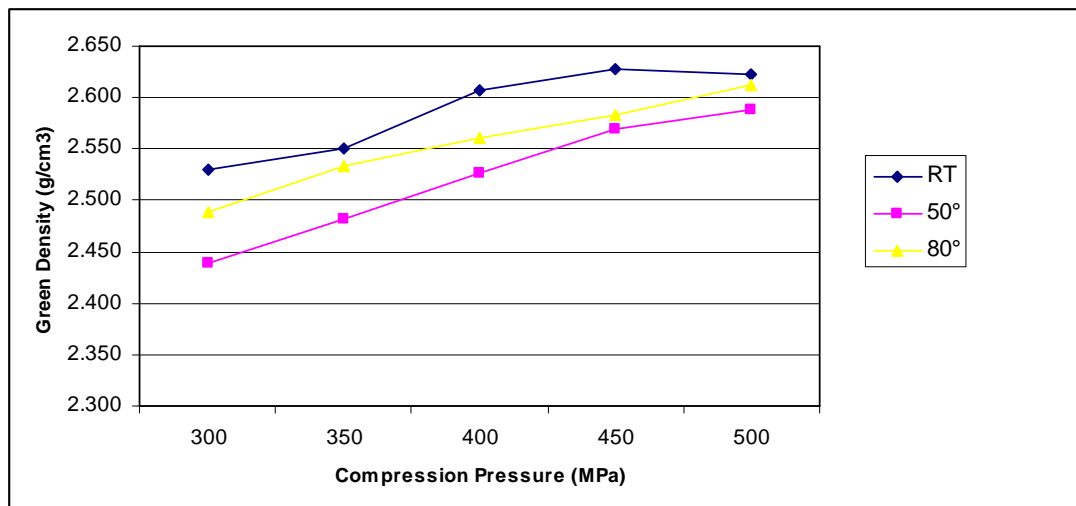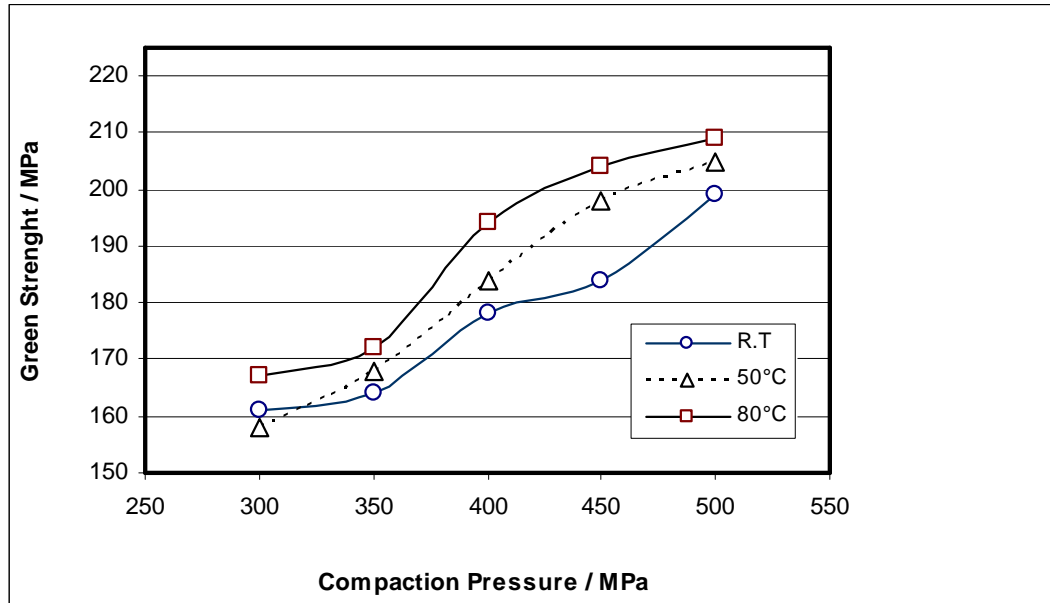
Electrical resistivity is a significant feature related to material, and is generally dependent upon the temperature. At room temperature, ρ value is representer of if a material is an insulator (ρ is on the order of $10^6\Omega$m) or a metal (ρ is on the order of 10^{-6} Ωm or less). Among the metal and insulator orders, semiconductor materials' resistivity values are low from materials. For the thermoelectric material the optimum electrical resistivity range is varied from 10^{-3} to $10^{-2}\Omega$m.

In metallic compounds, the analysis of the electrical resistivity related the temperature is an effective tool to acquire knowledge related the main features of these materials.

Alumix 1 is a the best material according to the other materials over 230K and ρ is roughly constant and the size and temperature related of ρ in the material is like to sighted in wicked metals or heavy added semiconductors (electrical resistivity of 0.13482 Ωm   at 230 K) indicated   as figure 4.7. Also the decreases show the specifial metallic behavior of the alumix 431 systems.
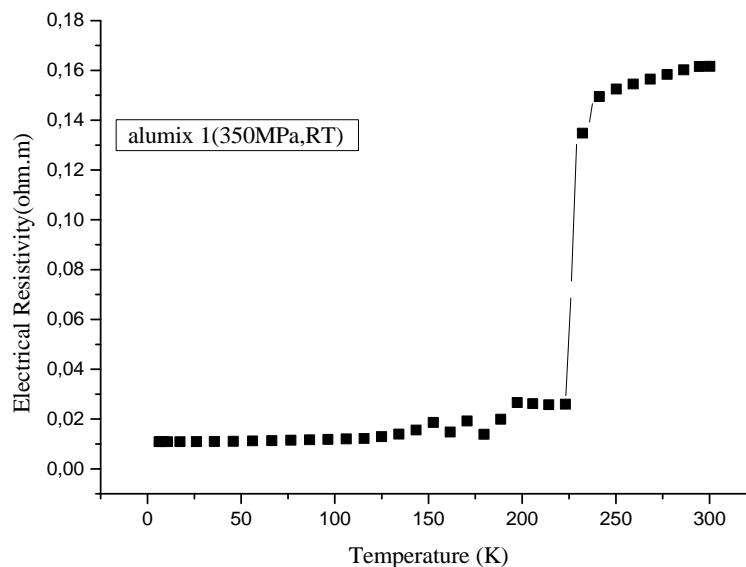

Figure 4.9. The Resistivity –Temperature graph of alumix(431) 1

For alumix 1 specimen; such a tendency is ascribed to a falling offset of E_F from the valley of the pseudegap. E_F moves to the location with larger density of states (DOS) leading to the decreasing in the electrical resistivity magnitude. The sample also indicates reducing of the same tendency with an inceptive step. The explanation for this case can be related to electrical conductivity that is electrical conductivity is based on the degree of texture; the conductivity increases with the increasing of the texture strength.

In the Figure 4.7., the sharp rise was exhibited. This case was considered to originate the impurity phases developed in the base matrix and weak inter-granular matchup. Development of both impurity phases and constitution of weak matchup among the impurities and alumix 431 grains acts a significant role in reducing the transition temperature (T_c) and increasing in the normal state resistance. As a result of in the figure the linear increase is means to a metallic behaviour down to transition temperature (T_c) (Aksan et al. , 2006, 2007).

For alumix 3 sample, the $\rho(T)$ relation of alumix 3 system, nearly resembles nonmagnetic amorphs alloys with Pauli paramagnetism of conductivity electrons. Also, in the graph in Figure 4.8. , at 225-275 K, this case is explained that on the electrical resistivity, both the constitution and resolution of η' phase and the constitution of η phase possess a powerful effect. This effect is more than inclined via the development of Guinier – Preston (GP) zones. The development is based on the a small peak centered at 225 K. The reason for this result may be less in flaws' concentration and sprinkling because of the slow cooling process. The process is required for the constitutions of the GP zones. The linear increase of alumix 3 specimen shows the favorable action inside the Baym-Meisel-Cote theory that regards the inelastic electron-phonon reaction. Below the Debye temperature θ_D, at temperatures, for the electron transport this case is important (Figure 4.8.).(Smontara et al., 2007)

Figure 4.10. The Resistivity –Temperature graph of alumix(431) 3

In alumix 1, 3, 4, 6 samples, it is indicated that an abrupt jump in similarity of the structural transition at different temperatures. With respect to resistivity magnitude, in agreement with behavior indicated via thermoelectric power. Alumix 431 samples is reckoned through hole transport, as proved via positive sign of the Seebeck effect. (see Figure 4.7-10)(Carlini et al., 2014)

Figure 4.11. The Resistivity –Temperature graph of alumix(431) 4

Figure 4.12. The Resistivity –Temperature graph of alumix(431) 6

In alumix 1(25-225K) (Figure 4.7.), alumix 2(5-300K) (Figure 4.11) alumix 6(at 30-195K), (Figure 4.10.), alumix 5(at 10-180K) (Figure 4.12.), alumix 4(25-115K) (Figure 4.14), (Figure 4.15) specimens, the resistivity values rise from 8.2×10^{-4} to 1.1×10^{-3} for alumix 1, from 0.0217 to 00445 for alumix 2; from 2.7×10^{-4} to 3.2×10^{-4} for alumix 4, from 4.72×10^{-4} to 7.60×10^{-4} for alumix 5; from 5×10^{-4} to 6.5×10^{-4} for alumix 6. The increases exhibited the consistent of the electrical resistivity hoped for a degenerate semiconductor; increasing with temperature, probably because of acoustic phonon spreading. (Figure 4.11.) (Tsujii et al., 2011).

Figure 4.13. The Resistivity –Temperature graph of alumix(431) 2
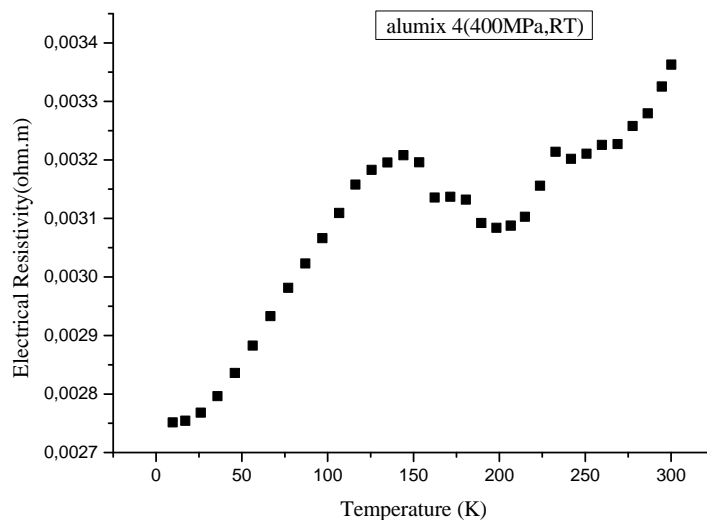
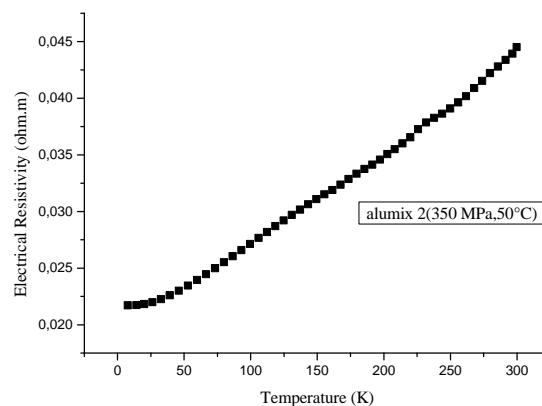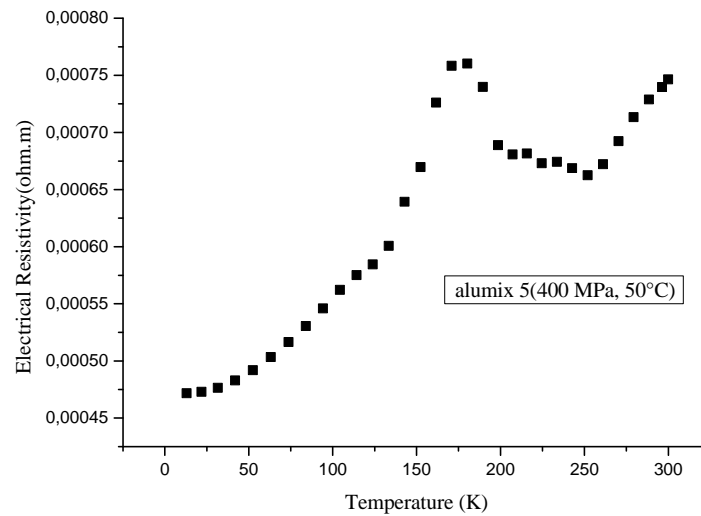Figure 4.14. The Resistivity –Temperature graph of alumix(431) 5

In alumix (431)4, 5, 6 samples, the graphs (Figure 4.9-11) are signed the A, B, C, D, E, F characters. The characters are stated the properties of alumix 431 systems whether the solutions, transitions, diffusions or not. AB, BC, CD, DE, EF are defined the a metallic transition because of spreading of electrons from isotropic centres, a semi insulating transition is commented as the constitution of either electron hole drop (EHD) or quantum well, semi metallic transition because of anisotropic spreading of electrons from gap or cracked sites, metalloid diffusion transitions and semi metallic diffusion (both are referred the a hybrid transition) respectively(Gormani et al., 1995).

In alumix 4 (144-189K) , alumix 5(at temperature range 180-207 K) alumix 6(at temperature range 210-245K), , the decreases in alumix (431) systems is clarified lowers the resistivity of from 3.2×10^{-4} Ωm, 7.60×10^{-4} Ωm 6.457×10^{-4} Ωm, and to 3.0923×10^{-4}Ωm 6.807×10^{-4} Ωm , 6.0657×10^{-4}, respectively, and produces a metallic conductors shown in Figures 4.1-14. These observings show that within these temperature ranges, there is a composition attribute that obtains semiconducting features while metallic behavior is sighted on both sides of these ranges.

In the decreases of the alumix (431) 4, 5, 6 systems,   the temperature related to mobility presents that the $\mu \alpha\ T^{-3/2}$ expression and the acoustic lattice scattering is

the predominant mechanism. Therefore, the increase in ρ at low temperature is clarified via the decrease in mobility with the increasing the temperature and the decrease is also explained conduction happens due to their band gap. The peaks also related with the sequence of the constitution and resolution of metastable phases(Tani and Kido, 2008).

In these materials the electrical resistivity values is based on the precipitation process of Al-Mg-Cu phases and their slight increases with a further increases in the temperature can be ascribed to the reducing amount of Al-Mg-Cu types precipitates in the alumix 431 structures at temperature ranges from 25 K to 200K, 175K, 180K respectively. These changes are rapid after 275K, 265K, and 285K respectively, as the resolution process dense, when Al-Mg-Cu type precipitates are no more stable. After 300 K, electrical resistivity value reaches the maximum value as the resolution of the alloying elements is rounded around. For alumix 1, 4, 5 samples gives the values of resistivity $6.46 \times 10^{-4} \Omega m$, $7.465 \times 10^{-4} \Omega m$ and $3.4 \times 10^{-4} \Omega m$ respectively.

4.5. Analysis of Thermal Conductivity Results of Alumix (431) 1, 2, 3, 4, 5, 6 Specimens

A high quality thermoelectric material must be required both a high electrical conductivity and a high thermopower and a low thermal conductivity as explained introduction section. The first two are specified via the electronic properties of the material, these are comprised into the quantity PF=$\alpha^2 \sigma$ defined to 'power factor'.

As a known, the thermal conductivity is stated with Wiedemann-Franz law expression; $\kappa = \kappa_e + \kappa_l$; in this expression; κ_e is transporting heat of carriers (electrons and holes), κ_l is expressed the travelling of phonons via the lattice. The thermoelectric figure of merit can be maximized through maximizing the electrical conductivity and minimizing the thermal conductivity.   Increasing of the electrical conductivity both generates an increase in the electronic thermal conductivity and reduces the thermopower.

Increasing of ZT value through the decreasing of both κ, and the lattice contribution to the thermal conductivity. The most significant factors acts role; i) utilizing of compounds ii) the existence of heavy atoms weakly linked to the structures iii) the presence of inclusions and/or impurities iv) the solid solutions' constitution, v) the presence of a large number of grain boundaries (Elsheikh et al., 2014).

In all the alumix (431) specimens, the increases in the thermal conductivity can be considered to originating   because of mainly the changes in lattice component term (κ_{ph}) (Demirel et al., 2014). Also these increases could be occurred because of the rapid reducing in electrical resistivity and accordingly strong increasing in the electronic thermal conductivity component κ_e (Gloria et al., 2013). Commonly it is ascribed to the porosity influence. High thermal conductivity was caused to low porosity position. In spite of that the thermal conductivity was increased with large grain size. This case is occurred because of decreasing grain boundary spreading of phonons (He et al., 2007).

For decreasing of all alumix 431 systems; the decreasing of κ originated the mass-variety scattering in the lattice of the alumix systems (Mikami et al., 2009).The Wiedemann-Franz law depend on the validity of the same the electron mean free path only at the low temperature for electrical and thermal transition. At low temperature, via flaws and impurities, the base electron spreading mechanism is elastic spreading mechanism. These low values show that electrons' elastic scattering acts   the important role through impurities and flaws at room temperatures (Carlini et al. 2014). Stronger phonon scattering was caused to the lowest thermal conductivity (Pan et al., 2010).

For all the samples, it was indicated that increases firstly and then decreases at final measured temperature. This case results from the decreasing of thermal spreading at low temperatures. as the phonon free path is taken after to crystal site distance, the maximum κ value happens (Kuo et al.2012).

For figure 4.13 and 4.14; in alumix 5, 6 samples, at 250-300K, it was exhibited the rising from 7.29 W/Km to 7.83 W/Km for alumix 5; from 17.806W/Km to 18.720W/Km for alumix 6,. To state of the origin of such a rapid

increasing of κ, two mechanisms can be proposed. One mechanism attributed to the increase of phonon mean free path electrons intensify into the copper pairs. Other alternative mechanism ascribed to the electron contribution. The rapid increase of κ below transition temperature (T_c) indicates improvement of the quasiparticle contribution the heat conductivity and increase of the quasiparticle mean-free path. The κ (T) reduced in magnitude and the location of maximum offsets against lower temperatures. The irregularities caused to impurities flaws act as a important role in restricting the heat transport because of a strong increase of the electron-phonon impurity spreading rate (Aksan et al. 2007).
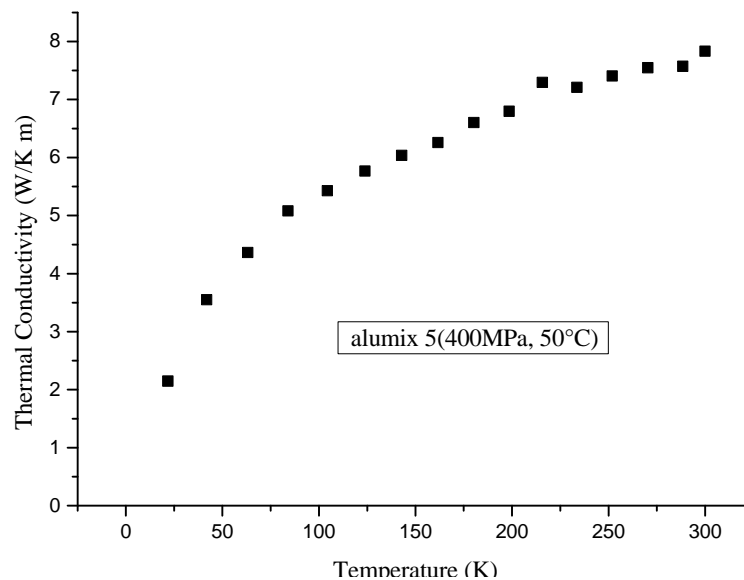

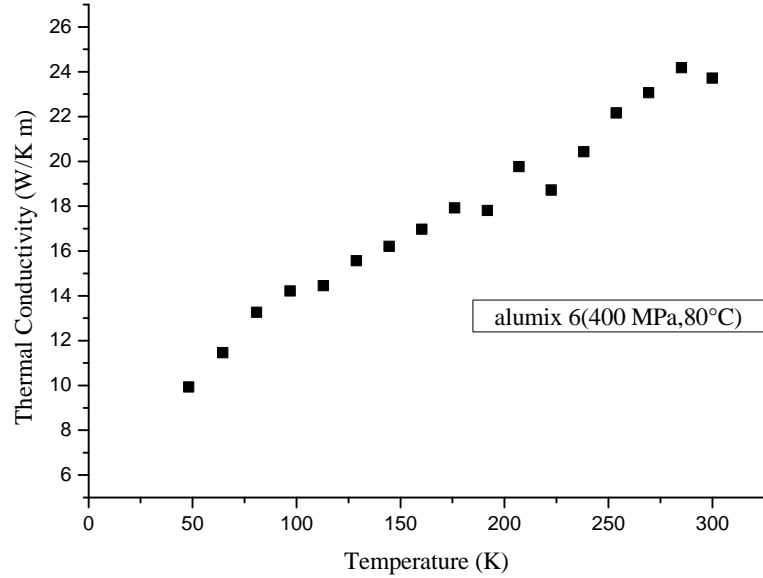Figure 4.15. The thermal conductivity –Temperature graph of alumix(431) 5

Figure 4.16. The thermal conductivity –Temperature graph of alumix(431) 6

In these graphs, it was indicated that two beginning transition temperatures. The temperatures remarked out two high T_c phases. Whereas the first transition is occurs because of η' phase progressively weaken, the second transition occurs owing to η phase becomes more impressive. Another possible reason for the reducing of the density is a decreasing in the phonon scattering inclined via flaws such as vacancies. (Özkurt et al., 2007) This case is occurred either electronic contribution or phononic contribution because of the reducing in phonon-carrier spreading and an increase in the phonon free path or both of them can be impressible (Aksan et al. 2007).

The same case exists in alumix 2, 3, 4 specimens. Only in this graphs quasiparticle life-span and quasiparticle mean free path abruptly increase in the superconducting state. This inclines in the electronic heat transport (Figure 4.20-22.) (Aksan et al., 2012).
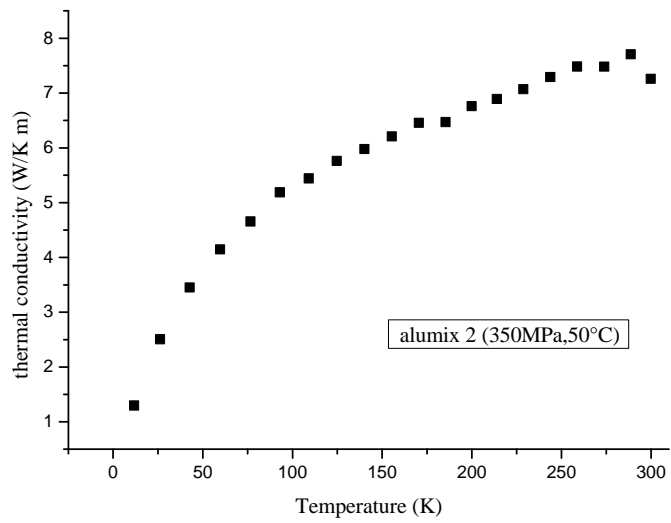
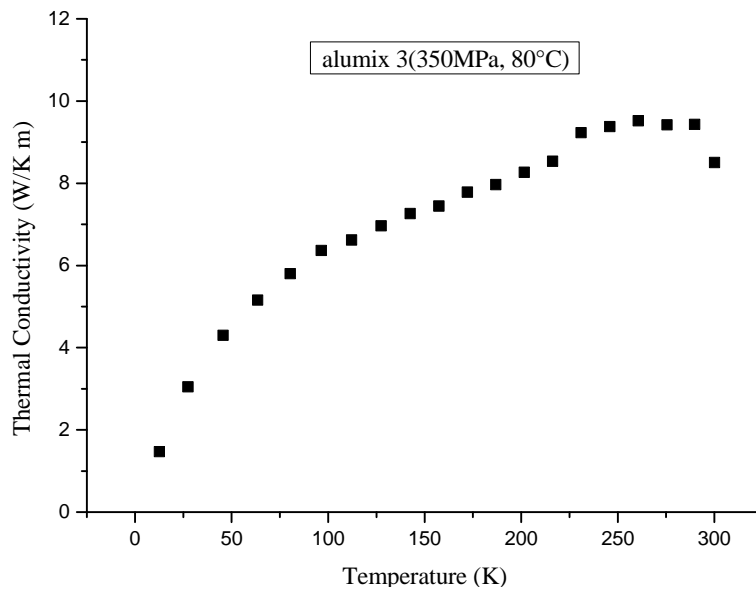Figure 4.17. The Thermal Conductivity –Temperature graph of alumix(431) 2

Figure 4.18. The Thermal Conductivity –Temperature graph of alumix(431) 3

Figure 4.19. The Thermal Conductivity –Temperature graph of alumix(431) 4

Figure 4.20. The Thermal Conductivity –Temperature graph of alumix(431) 1

4.6. Analysis of Seebeck Coefficient Results of Alumix(431) For 1, 2, 3, 4, 5, 6 Specimens

The Seebeck coefficient value is important physical property in reclaiming the potential performance of thermoelectric materials. The value is quite sensitive to the electronic structure and formulated by Mott's formula at a temperature T, for ordinary metals and semiconductors;

$$S(T) \propto T \left(\frac{\partial ln\sigma(E)}{\partial E} \right)_{E_T = E_F}$$

(4.1)

Where σ_E is stated the electrical conductivity as a function of energy (Kuo, et al. 2012).

In alumix 1 sample, a change in transport feature is appeared as the sign and the magnitude of S(T) change rapidly, demonstrating charge carriers varies from n- to p-type in figure 4.19.

Figure 4.21. The Seebeck Coefficient –Temperature graph of alumix(431) 1

For alumix 1 (at various temperatures), alumix 2 (at 60K), alumix 3 (at 172K) alumix 6 (at 164.23 K), Seebeck coefficient values of the 0.09372 µV/K , ,0.0507 µV/K, 0, 00187 µV/K, 0.0106 µV/K and respectively. Seebeck effect generated via both electrons and holes. Electrons and holes neutralize each other. The Fermi level can be offset from the lowest part of the pseudegap to a conduction band possessing a sharply increasing density of state (DOS) via electron doping in all the alumix 431 systems related on the rigid band model. After, the Seebeck coefficient increases as to Mott's equation. This equation proposes the Seebeck coefficient value is commensurate to the slope of the DOS at Fermi level. According to above equation, the negative effect of Seebeck coefficient is occurred via the increasing in the number of carriers, while the positive effect on the Seebeck coefficient is obtained from the increase in the slope of the DOS (figures 4.19-22) (Mikami et al., 2009).

Figure 4.22. The Seebeck Coefficient –Temperature graph of alumix(431) 2

Figure 4.23. The Seebeck Coefficient –Temperature graph of alumix(431) 3

Figure 4.24. The Seebeck Coefficient –Temperature graph of alumix(431) 6

At alumix 3,4,6 specimens in figures 4.24, 4.27 and 4.28; a change of S(T) sign says the existence of both positive (holes) and negative (electrons) types of carriers, this case show the multiband nature of the compounds. The positive contribution resulted from holes come from a powerful energy related to hole mobility, leading the positive TEP at higher temperatures. The figures exhibited that in the alumix systems, both the defects and dislocations increase. Also the extra scatter mechanism increases from both the impurity atoms and flaws and dislocations. This case induces to a increasing of the mean-free path of electron-hole pairs, and causes to positive effect on the TEP results (Özkurt et al., 2007).

Figure 4.25. The Seebeck Coefficient –Temperature graph of alumix(431) 4

Alumix 4, 5, 6 samples, it is explained that around the Fermi level, the electronic band structure is qualified via a small coincide of alumix conduction band minimum, comprising electron carriers, with a valence band maximum increasing

For alumix 5 and 6 specimens, valleys, at 0-150K temperature range, is explained the larger influence in lowering and imperfection the transition properties (the valleys of Seebeck coefficients; for alumix 5 sample, is -3.0657 µV/K at 90.82K, for alumix 6 sample, is -0.895 µV/K at 105K; (Figure 4.22 and 4.24)

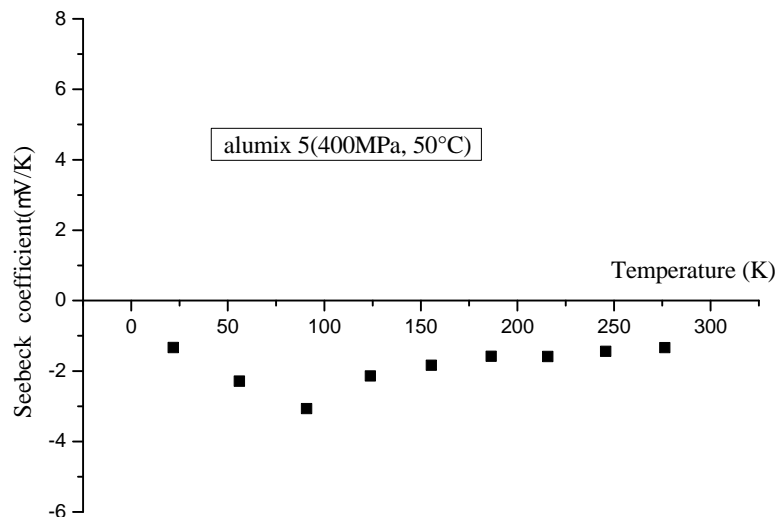Figure 4.26. The Seebeck Coefficient –Temperature graph of alumix(431) 5

In alumix 6 sample graph exhibited as figure 4.20., Seebeck coefficient values of alumix 1 at temperature ranges between 150-200K and 200-300K are 0.228 µV/K and 0.594 µV/K respectively, for this reason, the samples show positive peak, at the same time it was observed that samples indicated the negative peak at 50-100 K temperature range. This case is explained through the Kondo Effect and crystal electric field, the second positive peak is showed the spin fluctuations on its ground state. As a known the Kondo effect is occurred to the appeared upturn the resistance at low temperatures (Kouwenhoven and Glazman,2001; Kuwai et al., 2006) .

In alumix 6 sample graph, the Seebeck coefficient sign indicates positive value at temperature from 50 K to room temperature due to the having the holes which are the major conductivity carriers. But, in alumix 2 and 5 samples, the sign of Seebeck coefficient shows negative value for measured temperature range. This case is also explained that the major conductivity carriers are electrons (Park et al.). Electrons are the prevailing charge carriers in alumix 2 and 5 samples, while holes the dominant charge carriers in alumix 6 specimen (Smontara et al.). Seebeck coefficient is increased, when the more acute spreading carriers as the temperature is increase. The negative peak compressed with increasing the heat treatment time. The decreasing of phonon heat current causes to a decrease in phonon-drag effect. This effect is electron transported momentum. Hence, the negative peak is referred to phonon-drag effect (Aksan and Yakıncı, 2007). And then, the Seebeck coefficient decreases because of a rapid increase in carrier concentration with the increasing of the temperature.

Higher Seebeck coefficient is succeeded in higher porosity specimen. On the Seebeck coefficient, the grain size possesses the effect. When the number of both impurities and point flaws within grains slant to increase through the decreasing of the grain boundaries, with the rising spreading of carriers resulted via impurities and flaws, Seebeck coefficient increase (He et al.2007).

As a result; at all alumix 431 samples (except sample 2) presents an increasing tendency with the measurement temperature range while alumix 2 sample exhibited in figure 4.20. showed the decreasing tendency with sintering temperature

of 250-300K. This case is resulted from the increasing of electron concentration because of anti-structural defects constitution.

4.7. Analysis of Figure of Merit Results of Alumix (431) For 1, 2, 3, 4, 5, 6 Specimens

The dimensionless figure of merit, ZT, sums up the thermoelectric properties. The value is an important factor in choosing materials for thermoelectric power generation. The dimensionless figure of merit is reckoned from the electrical conductivity, Seebeck coefficient and thermal conductivity measured.

All the ZT of alumix (431) specimens related to the thermal conductivity besides the power factor (Tani and Kido, 2008).

For alumix 1, 3, 5 sample graphs, the small values of ZT in such a manner that for alumix 3 sample, the value is 1.527×10^{-10} at 214K ; for alumix 4 samples the value is 3.803×10^{-8} at 21.8K; for alumix 6 sample, 2.121×10^{-10} at 63.4K, are resulted from very large thermopower, low thermal conductivity and very high the electrical resistivity. Also their carrier concentrations are optimized (figure 4.25-27) (Zhang et al.,2009; Søndergaard et al., 2013).

Figure 4.27. The ZT –Temperature graph of alumix(431) 3

Figure 4.28. The ZT –Temperature graph of alumix(431) 3

Figure 4.29. The ZT –Temperature graph of alumix(431) 3

In alumix 2 specimen graph (figure 4.28.); the enhancement of the thermoelectric features is commonly originated from improved phonon scattering, increasing of electrical conductivity and mostly its lower electrical resistivity (Wang et al.2011 and Ahmadpour et al. 2007). Lower thermal conductivity and much lower

Seebeck coefficient which is seriously defacer to ZT is observed in alumix 3 sample graph as shown in figure 4.26. (Carlini et al., 2014).

Figure 4.30. The ZT –Temperature graph of alumix(431) 2

In figures 4.30 and 4.31; for alumix 4 and 6 specimens, ZT decreases due to the increase of thermal conductivity and the highest ZT attains about 5.0×10^{-9} at 325 K by improvement of Seebeck   coefficient (Han et al.). Samples show valleys at the temperature ranges 110-260K (for alumix 1) and 130-190K (for alumix 5) due to η à η' phase transition. Also, it is preponderated with various effects such as larger thermal conductivity, smaller Seebeck coefficient, though its electrical resistivity is improved. This enhancements in the thermoelectric properties of alumix 6 and 4 specimens, arise from the reduce in both the electrical resistivity and lattice thermal conductivity which can be attributed to the increased holes concentration and improved phonon scattering (Pan et al.2010).

Figure 4.31. The ZT –Temperature graph of alumix(431) 4

Figure 4.32. The ZT –Temperature graph of alumix(431) 6

4. RESULTS AND DISCUSSIONS
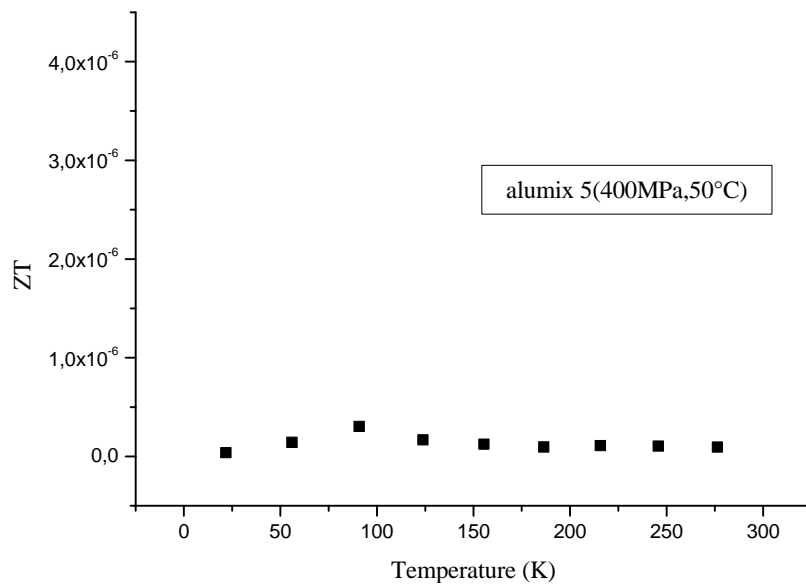
In this study, the thermoelectric properties of alumix (431) (Al-5.5 Zn-2.5Mg-1.5Cu) prepared on different pressures and temperatures have been investigated. It was examined Optical microscope, SEM images and density measurements of specimens for their structural properties and searched the electrical resistivity, thermal conductivity, Seebeck coefficient, the dimensionless figure of merit (ZT) data obtained from PPMS Quantum Design (Physical Property Measurement System) at measured temperature ranges 5-300 K for their thermoelectric properties.

In this study, the samples prepared on different pressures and temperatures were symbolized 1, 2, 3, 4, 5, 6

Alumix 1	350MPa, RT
Alumix 2	350MPa, 50°C
Alumix 3	350 MPa, 80°C
Alumix 4	400MPa, RT
Alumix 5	400MPA, 50°C
Alumix 6	400MPa, 80°C

4.1. Analysis of Optical Micrographic Figures of Alumix (431) 1, 2, 3, 4, 5 ,6 Specimens

In Figures 4.1, and 4.2, the badge microstructure of primary α-Al solid solution turned round via inter-dendritic secondary phases and some grain boundary precipitates having laminar morphology was shown. It was observed that the microstructures have the eutectic characteristic structure. In the microstructure, it is considered the existence of the coarse eutectic phases relating of the high amount of Zn, Mg and Cu in the alloys and low cooling rate linking to the traditional solidification process.

Figures 4.1 and 4.2 show the microstructure of Al-5.5Zn-2.5 Mg-1.5Cu alloy comprised of the both equiaxed grains and some fine secondary phases. The existence of the equiaxed grain morphology is considered to result from the high cooling rate, related to the rapid solidification processes. On the contrary, the existence of coarse eutectic phases in the IM counterpart processed traditionally was repressed.

In this Figures 4.1 and 4.2, it is also shown that second phases having both the grain boundaries and in the grain inners. The second phases in the grain inners reveal different shapes such as needle and square microstructure shape of particles. Along the matrix, most of the second phases is the comparative uniformly dispersed and it is sighted the some of the grain boundary precipitates possessing an allotriomorphic morphology (Feng et al. 2009)

The concentrated second phases have eutectic precipitated from the liquid phase directly at grain boundary. The distributed gray phases within the grains are mostly the strengthening phase ($MgZn_2$). The phase is precipitated from solid based body. In the microstructure, it was observed the some tiny pores. The pores decrease by the mechanical properties.

Figure 4.1. Optical microscope image of alumix (431) sample (50µm).

Figure 4.2. Optical microscope image of alumix (431) sample (20µm).

The cracks near the crack source zone of the fracture are intergranular microstructure. Course of events of deep into certain depth, the cracks transits into transcrystalline. Some coarse particles were sighted on the surface of the specimens. This case manifests the fatigue damage (see in Figure 4.3.) (Hai-Gen et al., 2009).

Figure 4.3. Optical microscope image of alumix (431) sample with transactions (10µm).

In the figure 4.4., ıt is observed that an equiaxed grains and two types of phases with apparent origins. The first one is the phase occurred at the grain boundaries throughout the solidification process led by the segregation of the alloying elements. The other phase is commonly constituted near the grain boundary. This case resulted from coring leading precipitation. Many coarse precipitates are apparent within the constituted grains (Mazzer et al. 2013).

Figure 4.4. Optical microscope image of alumix (431) sample with materials (20µm).

4.2. Analysis of SEM Figures of Alumix (431) 1, 2, 3, 4, 5, 6 Specimens

Figures 4.5-8 present the fracture surface of the samples. Many fine holes specified ductile resulted from fracture can be observed. Holes caused from the aged sample treated smaller than the solution heat treatment. It manifests the precipitated particles have affected the fracture occurred. At the grain and subgrain boundaries, the smaller holes are constituted because of the existence of the equilibrium η phase at these regions. This phase decrease the plastic deformation at the zone and the following plastic flow around the precipitates (Mazzer et al. 2013).

The precipitation behavior in α-Al matrix is related to the mechanical properties sized such as the ductility change and strength of various hot deformation treatments linked to size, dispersion and volume fraction of the precipitated second phases. It is observed the transgranular microstructures and fine holes with secondary cracks, in the figures. This case means the undissolved coarse phases caused to stress concentration. This stress concentration occurs in the constitution of the secondary cracks in the matrix and worsening influence on the ductility (Jia et al. 2012).

Deep and fewer holes were observed. The holes caused from including of secondary phases. It is considered the fracture of precipitates induced to the fracture. Naturally aged joints showed the fracture surface surrounded with deeper and larger holes besides few flat zones. Some deep hollows can be observed on the surface of the fracture (Figures 4.5-8) (Sharma et al. 2013).

The surface of fractures showed the mainly cup-cone holes with changing and no such intergranular cracks are seen. This case is explained the ductile fracture, non-similar intergranular brittle failure (Rout et al. 2014).

Figure 4.5. SEM image of Alumix (431) sample prepared under the 180MPa and 80°
          conditions(10µm).

Figure 4.6. SEM image of Alumix (431) sample prepared under the 180MPa and 80°
          C conditions (20µm).

4.3. Density Measurements of Alumix 431 Specimens

The results of the density measurements of Alumix 431 indicates the highest density on compacted specimen at 400MPa/RT. It was observed the decreasing porosity and homogeneous structure with increasing temperature. This case is shown that the density was influenced directly with decreasing porosity and shrinkage of pores was generated because of reducing of volume of sintered parts and non-varied weight. Therefore, these conditions increased the density. High density is resulted from high strength of sintered parts and high density also influences mechanical properties such as strength, toughness and hardness. For this reason, high density property is a desirable feature (İynen et al., 2010)(Figure 3.1-2).

Figure 4.7. The green density (g/cm^3) changes of Alumix 431 samples related to compression pressure(MPa)(İynen,2009).

Figure 4.8. Relationship between the compaction pressure and green strength of the samples prepared in three various compaction temperatures (İynen,2009).

4.4. Analysis of Electrical Resistivity Results of Alumix (431) 1, 2, 3, 4, 5, 6 Specimens

Electrical resistivity is a significant feature related to material, and is generally dependent upon the temperature. At room temperature, ρ value is represenser of if a material is an insulator (ρ is on the order of $10^6 \Omega$m) or a metal (ρ is on the order of 10^{-6} Ωm or less). Among the metal and insulator orders, semiconductor materials' resistivity values are low from materials. For the thermoelectric material the optimum electrical resistivity range is varied from 10^{-3} to $10^{-2} \Omega$m.

In metallic compounds, the analysis of the electrical resistivity related the temperature is an effective tool to acquire knowledge related the main features of these materials.

Alumix 1 is a the best material according to the other materials over 230K and ρ is roughly constant and the size and temperature related of ρ in the material is like to sighted in wicked metals or heavy added semiconductors (electrical resistivity of 0.13482 Ωm   at 230 K) indicated   as figure 4.7. Also the decreases show the specifial metallic behavior of the alumix 431 systems.

Figure 4.9. The Resistivity –Temperature graph of alumix(431) 1

For alumix 1 specimen; such a tendency is ascribed to a falling offset of E_F from the valley of the pseudegap. E_F moves to the location with larger density of states (DOS) leading to the decreasing in the electrical resistivity magnitude. The sample also indicates reducing of the same tendency with an inceptive step. The explanation for this case can be related to electrical conductivity that is electrical conductivity is based on the degree of texture; the conductivity increases with the increasing of the texture strength.

In the Figure 4.7., the sharp rise was exhibited. This case was considered to originate the impurity phases developed in the base matrix and weak inter-granular matchup. Development of both impurity phases and constitution of weak matchup among the impurities and alumix 431 grains acts a significant role in reducing the transition temperature (T_c) and increasing in the normal state resistance. As a result of in the figure the linear increase is means to a metallic behaviour down to transition temperature (T_c) (Aksan et al. , 2006, 2007).

For alumix 3 sample, the $\rho(T)$ relation of alumix 3 system, nearly resembles nonmagnetic amorphs alloys with Pauli paramagnetism of conductivity electrons. Also, in the graph in Figure 4.8. , at 225-275 K, this case is explained that on the electrical resistivity, both the constitution and resolution of η' phase and the constitution of η phase possess a powerful effect. This effect is more than inclined via the development of Guinier – Preston (GP) zones. The development is based on the a small peak centered at 225 K. The reason for this result may be less in flaws' concentration and sprinkling because of the slow cooling process. The process is required for the constitutions of the GP zones. The linear increase of alumix 3 specimen shows the favorable action inside the Baym-Meisel-Cote theory that regards the inelastic electron-phonon reaction. Below the Debye temperature θ_D, at temperatures, for the electron transport this case is important (Figure 4.8.).(Smontara et al., 2007)

Figure 4.10. The Resistivity –Temperature graph of alumix(431) 3

In alumix 1, 3, 4, 6 samples, it is indicated that an abrupt jump in similarity of the structural transition at different temperatures. With respect to resistivity magnitude, in agreement with behavior indicated via thermoelectric power. Alumix 431 samples is reckoned through hole transport, as proved via positive sign of the Seebeck effect. (see Figure 4.7-10)(Carlini et al., 2014)

Figure 4.11. The Resistivity –Temperature graph of alumix(431) 4

Figure 4.12. The Resistivity –Temperature graph of alumix(431) 6

In alumix 1(25-225K) (Figure 4.7.), alumix 2(5-300K) (Figure 4.11) alumix 6(at 30-195K), (Figure 4.10.), alumix 5(at 10-180K) (Figure 4.12.), alumix 4(25-115K) (Figure 4.14), (Figure 4.15) specimens, the resistivity values rise from $8.2{\times}10^{-4}$ to $1.1{\times}10^{-3}$ for alumix 1, from 0.0217 to 00445 for alumix 2; from $2.7{\times}10^{-4}$ to $3.2{\times}10^{-4}$ for alumix 4, from $4.72 {\times}10^{-4}$ to $7.60{\times}10^{-4}$ for alumix 5; from $5{\times}10^{-4}$ to $6.5 {\times}10^{-4}$ for alumix 6. The increases exhibited the consistent of the electrical resistivity hoped for a degenerate semiconductor; increasing with temperature, probably because of acoustic phonon spreading. (Figure 4.11.) (Tsujii et al., 2011).

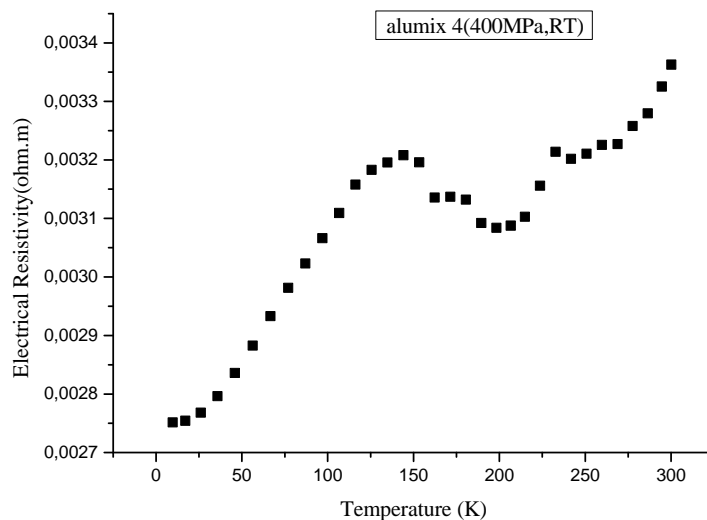

Figure 4.13. The Resistivity –Temperature graph of alumix(431) 2

Figure 4.14. The Resistivity –Temperature graph of alumix(431) 5

In alumix (431)4, 5, 6 samples, the graphs (Figure 4.9-11) are signed the A, B, C, D, E, F characters. The characters are stated the properties of alumix 431 systems whether the solutions, transitions, diffusions or not. AB, BC, CD, DE, EF are defined the a metallic transition because of spreading of electrons from isotropic centres, a semi insulating transition is commented as the constitution of either electron hole drop (EHD) or quantum well, semi metallic transition because of anisotropic spreading of electrons from gap or cracked sites, metalloid diffusion transitions and semi metallic diffusion (both are referred the a hybrid transition) respectively(Gormani et al., 1995).

In alumix 4 (144-189K) , alumix 5(at temperature range 180-207 K) alumix 6(at temperature range   210-245K), , the decreases in alumix (431) systems is clarified lowers the resistivity of from 3.2×10^{-4} Ωm, 7.60×10^{-4} Ωm 6.457×10^{-4} Ωm, and to $3.0923 \times 10^{-4}$$\Omega$m 6.807×10^{-4} Ωm , 6.0657×10^{-4}, respectively, and produces a metallic conductors shown in Figures 4.1-14. These observings show that within these temperature ranges, there is a composition attribute that obtains semiconducting features while metallic behavior is sighted on both sides of these ranges.

In the decreases of the alumix (431) 4, 5, 6 systems,   the temperature related to mobility presents that the $\mu \alpha$ $T^{-3/2}$ expression and the acoustic lattice scattering is

the predominant mechanism. Therefore, the increase in ρ at low temperature is clarified via the decrease in mobility with the increasing the temperature and the decrease is also explained conduction happens due to their band gap. The peaks also related with the sequence of the constitution and resolution of metastable phases(Tani and Kido, 2008).

In these materials the electrical resistivity values is based on the precipitation process of Al-Mg-Cu phases and their slight increases with a further increases in the temperature can be ascribed to the reducing amount of Al-Mg-Cu types precipitates in the alumix 431 structures at temperature ranges from 25 K to 200K, 175K, 180K respectively. These changes are rapid after 275K, 265K, and 285K respectively, as the resolution process dense, when Al-Mg-Cu type precipitates are no more stable. After 300 K, electrical resistivity value reaches the maximum value as the resolution of the alloying elements is rounded around. For alumix 1, 4, 5 samples gives the values of resistivity $6.46 \times 10^{-4} \Omega m$, $7.465 \times 10^{-4} \Omega m$ and $3.4 \times 10^{-4} \Omega m$ respectively.

4.5. Analysis of Thermal Conductivity Results of Alumix (431) 1, 2, 3, 4, 5, 6 Specimens

A high quality thermoelectric material must be required both a high electrical conductivity and a high thermopower and a low thermal conductivity as explained introduction section. The first two are specified via the electronic properties of the material, these are comprised into the quantity PF=$\alpha^2 \sigma$ defined to 'power factor'.

As a known, the thermal conductivity is stated with Wiedemann-Franz law expression; $\kappa = \kappa_e + \kappa_l$; in this expression; κ_e is transporting heat of carriers (electrons and holes), κ_l is expressed the travelling of phonons via the lattice. The thermoelectric figure of merit can be maximized through maximizing the electrical conductivity and minimizing the thermal conductivity. Increasing of the electrical conductivity both generates an increase in the electronic thermal conductivity and reduces the thermopower.

Increasing of ZT value through the decreasing of both κ, and the lattice contribution to the thermal conductivity. The most significant factors acts role; i) utilizing of compounds ii) the existence of heavy atoms weakly linked to the structures iii) the presence of inclusions and/or impurities iv) the solid solutions' constitution, v) the presence of a large number of grain boundaries (Elsheikh et al., 2014).

In all the alumix (431) specimens, the increases in the thermal conductivity can be considered to originating   because of mainly the changes in lattice component term (κ_{ph}) (Demirel et al., 2014). Also these increases could be occurred because of the rapid reducing in electrical resistivity and accordingly strong increasing in the electronic thermal conductivity component κ_e (Gloria et al., 2013). Commonly it is ascribed to the porosity influence. High thermal conductivity was caused to low porosity position. In spite of that the thermal conductivity was increased with large grain size. This case is occurred because of decreasing grain boundary spreading of phonons (He et al., 2007).

For decreasing of all alumix 431 systems; the decreasing of κ originated the mass-variety scattering in the lattice of the alumix systems (Mikami et al., 2009).The Wiedemann-Franz law depend on the validity of the same the electron mean free path only at the low temperature for electrical and thermal transition. At low temperature, via flaws and impurities, the base electron spreading mechanism is elastic spreading mechanism. These low values show that electrons' elastic scattering acts   the important role through impurities and flaws at room temperatures (Carlini et al. 2014). Stronger phonon scattering was caused to the lowest thermal conductivity (Pan et al., 2010).

For all the samples, it was indicated that increases firstly and then decreases at final measured temperature. This case results from the decreasing of thermal spreading at low temperatures. as the phonon free path is taken after to crystal site distance, the maximum κ value happens (Kuo et al.2012).

For figure 4.13 and 4.14; in alumix 5, 6 samples, at 250-300K, it was exhibited the rising from 7.29 W/Km to 7.83 W/Km for alumix 5; from 17.806W/Km to 18.720W/Km for alumix 6,. To state of the origin of such a rapid

increasing of κ, two mechanisms can be proposed. One mechanism attributed to the increase of phonon mean free path electrons intensify into the copper pairs. Other alternative mechanism ascribed to the electron contribution. The rapid increase of κ below transition temperature (T_c) indicates improvement of the quasiparticle contribution the heat conductivity and increase of the quasiparticle mean-free path. The κ (T) reduced in magnitude and the location of maximum offsets against lower temperatures. The irregularities caused to impurities flaws act as a important role in restricting the heat transport because of a strong increase of the electron-phonon impurity spreading rate (Aksan et al. 2007).

Figure 4.15. The thermal conductivity –Temperature graph of alumix(431) 5

Figure 4.16. The thermal conductivity –Temperature graph of alumix(431) 6

In these graphs, it was indicated that two beginning transition temperatures. The temperatures remarked out two high T_c phases. Whereas the first transition is occurs because of η' phase progressively weaken, the second transition occurs owing to η phase becomes more impressive. Another possible reason for the reducing of the density is a decreasing in the phonon scattering inclined via flaws such as vacancies. (Özkurt et al., 2007) This case is occurred either electronic contribution or phononic contribution because of the reducing in phonon-carrier spreading and an increase in the phonon free path or both of them can be impressible (Aksan et al. 2007).

The same case exists in alumix 2, 3, 4 specimens. Only in this graphs quasiparticle life-span and quasiparticle mean free path abruptly increase in the superconducting state. This inclines in the electronic heat transport (Figure 4.20-22.) (Aksan et al., 2012).
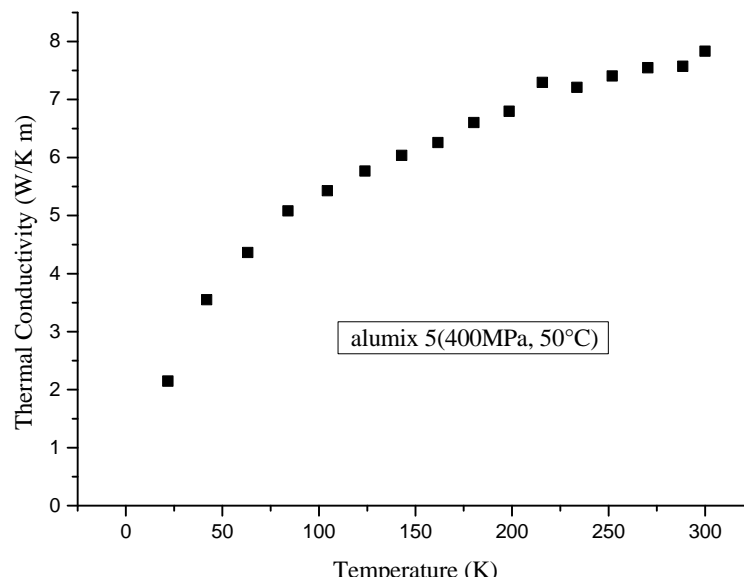
Figure 4.17. The Thermal Conductivity –Temperature graph of alumix(431) 2

Figure 4.18. The Thermal Conductivity –Temperature graph of alumix(431) 3

Figure 4.19. The Thermal Conductivity –Temperature graph of alumix(431) 4

Figure 4.20. The Thermal Conductivity –Temperature graph of alumix(431) 1

4.6. Analysis of Seebeck Coefficient Results of Alumix(431) For 1, 2, 3, 4, 5, 6 Specimens

The Seebeck coefficient value is important physical property in reclaiming the potential performance of thermoelectric materials. The value is quite sensitive to the electronic structure and formulated by Mott's formula at a temperature T, for ordinary metals and semiconductors;

$$S(T) \propto T \left(\frac{\partial ln\sigma(E)}{\partial E} \right)_{E_T = E_F}$$

(4.1)

Where σ_E is stated the electrical conductivity as a function of energy (Kuo, et al. 2012).

In alumix 1 sample, a change in transport feature is appeared as the sign and the magnitude of S(T) change rapidly, demonstrating charge carriers varies from n- to p-type in figure 4.19.

Figure 4.21. The Seebeck Coefficient –Temperature graph of alumix(431) 1

For alumix 1 (at various temperatures), alumix 2 (at 60K), alumix 3 (at 172K) alumix 6 (at 164.23 K), Seebeck coefficient values of the 0.09372 µV/K , ,0.0507 µV/K, 0, 00187 µV/K, 0.0106 µV/K and respectively. Seebeck effect generated via both electrons and holes. Electrons and holes neutralize each other. The Fermi level can be offset from the lowest part of the pseudegap to a conduction band possessing a sharply increasing density of state (DOS) via electron doping in all the alumix 431 systems related on the rigid band model. After, the Seebeck coefficient increases as to Mott's equation. This equation proposes the Seebeck coefficient value is commensurate to the slope of the DOS at Fermi level. According to above equation, the negative effect of Seebeck coefficient is occurred via the increasing in the number of carriers, while the positive effect on the Seebeck coefficient is obtained from the increase in the slope of the DOS (figures 4.19-22) (Mikami et al., 2009).

Figure 4.22. The Seebeck Coefficient –Temperature graph of alumix(431) 2

Figure 4.23. The Seebeck Coefficient –Temperature graph of alumix(431) 3

Figure 4.24. The Seebeck Coefficient –Temperature graph of alumix(431) 6

At alumix 3,4,6 specimens in figures 4.24, 4.27 and 4.28; a change of S(T) sign says the existence of both positive (holes) and negative (electrons) types of carriers, this case show the multiband nature of the compounds. The positive contribution resulted from holes come from a powerful energy related to hole mobility, leading the positive TEP at higher temperatures. The figures exhibited that in the alumix systems, both the defects and dislocations increase. Also the extra scatter mechanism increases from both the impurity atoms and flaws and dislocations. This case induces to a increasing of the mean-free path of electron-hole pairs, and causes to positive effect on the TEP results (Özkurt et al., 2007).

Figure 4.25. The Seebeck Coefficient –Temperature graph of alumix(431) 4

Alumix 4, 5, 6 samples, it is explained that around the Fermi level, the electronic band structure is qualified via a small coincide of alumix conduction band minimum, comprising electron carriers, with a valence band maximum increasing

For alumix 5 and 6 specimens, valleys, at 0-150K temperature range, is explained the larger influence in lowering and imperfection the transition properties (the valleys of Seebeck coefficients; for alumix 5 sample, is -3.0657 µV/K at 90.82K, for alumix 6 sample, is -0.895 µV/K at 105K; (Figure 4.22 and 4.24)

Figure 4.26. The Seebeck Coefficient –Temperature graph of alumix(431) 5

In alumix 6 sample graph exhibited as figure 4.20., Seebeck coefficient values of alumix 1 at temperature ranges between 150-200K and 200-300K are 0.228 µV/K and 0.594 µV/K respectively, for this reason, the samples show positive peak, at the same time it was observed that samples indicated the negative peak at 50-100 K temperature range. This case is explained through the Kondo Effect and crystal electric field, the second positive peak is showed the spin fluctuations on its ground state. As a known the Kondo effect is occurred to the appeared upturn the resistance at low temperatures (Kouwenhoven and Glazman,2001; Kuwai et al., 2006) .

In alumix 6 sample graph, the Seebeck coefficient sign indicates positive value at temperature from 50 K to room temperature due to the having the holes which are the major conductivity carriers. But, in alumix 2 and 5 samples, the sign of Seebeck coefficient shows negative value for measured temperature range. This case is also explained that the major conductivity carriers are electrons (Park et al.). Electrons are the prevailing charge carriers in alumix 2 and 5 samples, while holes the dominant charge carriers in alumix 6 specimen (Smontara et al.). Seebeck coefficient is increased, when the more acute spreading carriers as the temperature is increase. The negative peak compressed with increasing the heat treatment time. The decreasing of phonon heat current causes to a decrease in phonon-drag effect. This effect is electron transported momentum. Hence, the negative peak is referred to phonon-drag effect (Aksan and Yakıncı, 2007). And then, the Seebeck coefficient decreases because of a rapid increase in carrier concentration with the increasing of the temperature.

Higher Seebeck coefficient is succeeded in higher porosity specimen. On the Seebeck coefficient, the grain size possesses the effect. When the number of both impurities and point flaws within grains slant to increase through the decreasing of the grain boundaries, with the rising spreading of carriers resulted via impurities and flaws, Seebeck coefficient increase (He et al.2007).

As a result; at all alumix 431 samples (except sample 2) presents an increasing tendency with the measurement temperature range while alumix 2 sample exhibited in figure 4.20. showed the decreasing tendency with sintering temperature

of 250-300K. This case is resulted from the increasing of electron concentration because of anti-structural defects constitution.

4.7. Analysis of Figure of Merit Results of Alumix (431) For 1, 2, 3, 4, 5, 6 Specimens

The dimensionless figure of merit, ZT, sums up the thermoelectric properties. The value is an important factor in choosing materials for thermoelectric power generation. The dimensionless figure of merit is reckoned from the electrical conductivity, Seebeck coefficient and thermal conductivity measured.

All the ZT of alumix (431) specimens related to the thermal conductivity besides the power factor (Tani and Kido, 2008).

For alumix 1, 3, 5 sample graphs, the small values of ZT in such a manner that for alumix 3 sample, the value is 1.527×10^{-10} at 214K ; for alumix 4 samples the value is 3.803×10^{-8} at 21.8K; for alumix 6 sample, 2.121×10^{-10} at 63.4K, are resulted from very large thermopower, low thermal conductivity and very high the electrical resistivity. Also their carrier concentrations are optimized (figure 4.25-27) (Zhang et al.,2009; Søndergaard et al., 2013).

Figure 4.27. The ZT –Temperature graph of alumix(431) 3

Figure 4.28. The ZT –Temperature graph of alumix(431) 3

Figure 4.29. The ZT –Temperature graph of alumix(431) 3

In alumix 2 specimen graph (figure 4.28.); the enhancement of the thermoelectric features is commonly originated from improved phonon scattering, increasing of electrical conductivity and mostly its lower electrical resistivity (Wang et al.2011 and Ahmadpour et al. 2007). Lower thermal conductivity and much lower

Seebeck coefficient which is seriously defacer to ZT is observed in alumix 3 sample graph as shown in figure 4.26. (Carlini et al., 2014).

Figure 4.30. The ZT –Temperature graph of alumix(431) 2

In figures 4.30 and 4.31; for alumix 4 and 6 specimens, ZT decreases due to the increase of thermal conductivity and the highest ZT attains about 5.0×10^{-9} at 325 K by improvement of Seebeck   coefficient (Han et al.). Samples show valleys at the temperature ranges 110-260K (for alumix 1) and 130-190K (for alumix 5) due to η à η' phase transition. Also, it is preponderated with various effects such as larger thermal conductivity, smaller Seebeck coefficient, though its electrical resistivity is improved. This enhancements in the thermoelectric properties of alumix 6 and 4 specimens, arise from the reduce in both the electrical resistivity and lattice thermal conductivity which can be attributed to the increased holes concentration and improved phonon scattering (Pan et al.2010).

Figure 4.31. The ZT –Temperature graph of alumix(431) 4

Figure 4.32. The ZT –Temperature graph of alumix(431) 6

5. CONCLUSION

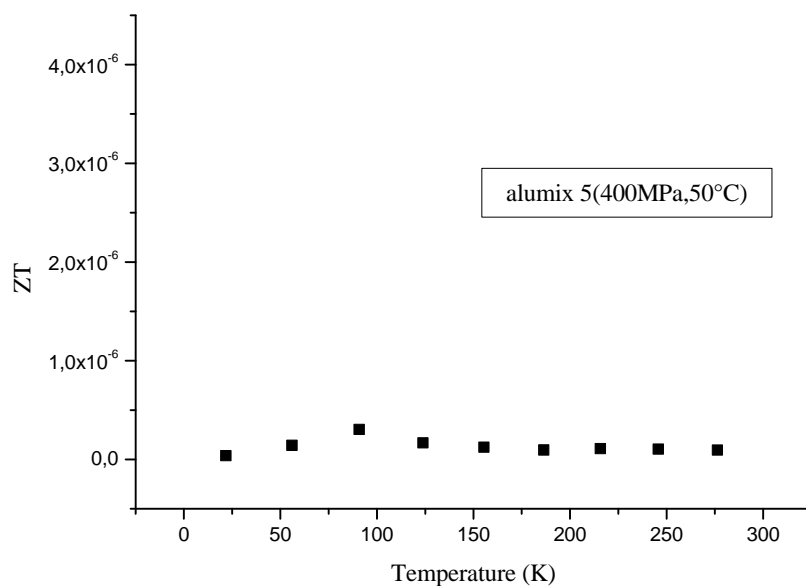Thermoelectric materials transform waste heat from industrial waste, automobile exhaust gases etc. to electricity energy using Seebeck effect. The effect is conversion of temperature changed directly and the devices worked with this effect are known as Seebeck generators. In the other words, the devices generate heat flow between coupling of two various types of material using Peltier effect. The devices occurring with the effect and   applies to coolers, due to this reason the devices are referred the Peltier coolers.

A thermoelectric device consists of an element put between a heat source and heat sink. Heat transfer is occurred from the source to the sink via the carriers (or electrons) motion or lattices. The efficiency of thermoelectric devices is stated by dimensionless figure of merit (ZT) of thermoelectric materials. The figure of merit is determined calculating of electrical resistivity, thermal conductivity, Seebeck coefficient values.

A high quality thermoelectric material is necessitated for a high electrical conductivity, high thermopower and the low thermal conductivity, high ZT values these properties related to each other. In the Hall Effect, Seebeck coefficient and resistivity will be low so as to maximize ZT materials.

Thermoelectric materials are classified by the temperature rang of their implementation areas: Bi_2Te_3 alloys, PbTe based alloys and TAGS, SiGe alloys. The Fabrication Methods of the thermoelectric materials are; crystal growth methods, thin film methods, powder based methods.

In the previous study section, it reviewed the production methods of thermoelectric materials and the thermoelectric properties (electrical conductivity and resistivity) of Al7xxx materials. It wasn't studied about the Seebeck coefficient, figure of merit of Al 7xxx series alloys. In this study, it was investigated the thermoelectric properties with Seebeck coefficient and figure of merit of Alumix 431 material which is Al 7xxx alloy.

In this study Alumix 431 (Al-5.5Zn-2.5Mg-1.5Cu) prepared by conventional pres and sintering method on different pressure and temperatures. The structural

properties of Alumix 431 material was investigated on the light microscope(Leica DMRX) and SEM (LEO 1530 GEMINI) microscope images and density testing measuremet was doned by ARCHIMEDES Principle(water displacement tecnique Precisa 320XT series for analytical and precision balances in Gazi University's Mechanical Research Laboratory in Ankara, Turkey. The thermoelectric properties of Alumix 431 materials was measured by Model 6000 Physical Property Measured System at 5-300 K in İnönü Üniversity's Scientific an Technology Center in Malatya , Turkey.

The obtained experimental results show that at temperature range of 285-295 K, the maximum electrical resistivity and electrical conductivity were acquired 0.161Ωm(350 MPa, RT) (Alumix 1) and 24.96W/Km(400 MPa, 80°C) (Alumix 6), respectively, and the Seebeck Coefficient values changed mostly negative sign to positive sign due to dominate from carriers. Also, it was determined as 5.65×10^{-6} of the maximum figure of merit at 300K temperature(400MPa, RT)(Alumix 4).

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