

Self mass attenuation coefficients for mixture of some 3d elements

$Ni_{100-x} Al_x$ and $Zn_{100-x} - Al_x$ at Am-241(40mCi)

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Abstract - In this paper we study the mass attenuation coefficients (μ_m) for $Ni_{100-x} Al_x$, $Zn_{100-x} Al_x$ mixtures with different weight ratios. These mixtures were prepared by mixing the Nickel (Ni) and Zinc (Zn) with different concentration of Al ($x = 10-50$) using ball milling technique. The mass attenuation coefficients (μ_m) were measured by self attenuation of characteristics X-rays. The Gamma rays of 59.6 KeV emitted from 241Am source were used to excite the mixture samples and emitted K_α and K_β X-ray lines were counted by a Silicon Drift Detector (SDD) with a resolution of 150 eV at 6.4 KeV. The samples have also been characterized by SEM and EDXRF measurements. The obtained results were compared with theoretical values and are agreement with theoretical results.

KeyWords - Mass attenuation coefficient, X-ray fluorescence, 3d transition elements, scanning electronic microscope (SEM), EDAX.

I. INTRODUCTION

In 1905, a decade after Roentgen discovered X-rays, the British physicist Charles Barkla found that a target struck by a beam of high energy X-rays (primary/incident beam) emitted secondary X-rays distinctly different in behavior from those in the incident beam. He discovered that the secondary X-rays emitted by a target are

unique to the chemical element the target is made of, so he called them characteristic X-rays, and pointed out that they could be used to identify the target Material. Barkla *et.al.* found that an anode emits two distinctly different types of characteristic X-rays, one more penetrating type (shorter wavelengths, higher energy) called K-shell X-ray radiation, and second one more easily absorbed (longer wavelengths, lower energy) called L-shell X-ray radiation. These emissions are called X-ray lines because they are analogous to the spectral lines in the visible light spectra of atoms and can work as a unique finger print of the emitter atom [1,2]. It is well known that when any radiation incident on the material it may get attenuated. Similarly the intensity of the incident X-ray is attenuated due to its interactions with atomic species which occur during the passage through the material. This attenuation is governed according to the exponential absorption law.

$$I_t = I_0 \exp [-(\mu/\rho) t] \quad (1)$$

Where μ/ρ is the mass attenuation coefficient, I_0 and I_t are the intensities of incident (unattenuated) and transmitted (attenuated) X-ray photons and t is the mass per unit area of the material. This equation can be used to obtain μ/ρ

from measured I_0 , I_t and t data. The mass attenuation coefficients are a measure of the average number of interactions that occur between the incident photons and mass per unit area [3]. These interactions are related to the atomic number of an element and the photon energy for a single element. The three major gamma ray interaction processes i.e. Photoelectric, Compton with coherent scattering and Pair production and can be expressed as a function of photon energy $h\nu$ and atomic number Z of the element. The photoelectric absorption is the dominant interaction, causes the generation of the characteristic X-rays in the sample. At a given photon energy [4-7] the interaction is proportional to Z^n where n is between 4 and 5 for Photoelectric effect. A number of experimental studies on mass attenuation coefficients and mixture rule have been reported and studied X-ray absorption coefficient for rubidium in the K-edge region [8-11]. In the literature description of mixtures of elements, it is standard practice to assume that the contribution of each element to the attenuation is additive. This assumption yields the well known mixture rule which gives the attenuation coefficient of any substance as the sum of the appropriately weighted contributions from the individual atoms [12-15]. Thus the mass attenuation coefficient μ_m is given by Equation (2).

$$\mu_m = \sum_i w_i \left(\frac{\mu}{\rho} \right)_i \quad (2)$$

where w_i is the proportion by weight, μ is the linear attenuation coefficient in cm^{-1} , ρ (g/cm^3) is the density of element and μ_m (cm^2/g) is the mass attenuation coefficient of constituent element i of the compound. The mixture rule is valid when the effects on the atomic wave function of molecular bonding and chemical or crystalline environment are negligible [16-18].

When all the energy ($E = h\nu$) of X-ray or γ -ray photon is used to release the electron from an atom or molecule, the process is called photoelectric effect. From the principle of

Conservation of energy, the kinetic energy of the electron so released is equal to the energy of the photon ($h\nu$) minus the binding energy of the electron to the atom. Binding energies of electrons in various shells are different and X-ray photons can ionize inner-shell electrons. Absorption of photons by photoelectric effect is the most important mode for low energy (long wavelength) photons, especially when the energy is just sufficient to eject electron ionization Braking radiation annihilation from a particular shell of the atoms in the medium. In the photoelectric effect the photon with an energy $E=h\nu$ is absorbed by the atom and its energy used for releasing electrons from the atomic system. The released photo electrons carry a kinetic energy E_k , which corresponds to the difference between the initial energy of the photon and the binding energy E_b necessary to release the electron from its atomic orbit by Equation (3).

$$E_k = h\nu - E_b \quad (3)$$

The ionization of the most tightly bound electrons in the K and the L shell of the atom contribute mostly to the photoelectric effect. The created vacancy in the K or L shell is filled quickly by subsequent de-excitation of electrons from the higher orbits with the emission of the characteristic X-rays. This process is called X-ray fluorescence. Alternatively to X-ray fluorescence, the released energy is used to ionize more, less bound electrons – the so-called Auger electrons. Since the lower energy X-rays and also the Auger electrons are mostly absorbed in the material by subsequent interaction processes, most of the initial photon energy is completely absorbed. In specific experimental configurations the characteristic X-rays escape and X-ray fluorescence can be observed [19, 20].

In present paper, the mass attenuation coefficients (μ_m) for mixture some 3 d transition elements ($\text{Ni}_{100-x} \text{Al}_x$, $\text{Zn}_{100-x} \text{Al}_x$) with different weight ratio by self attenuation method

using X-ray fluorescence will be studied. The sample mixtures were prepared by mixing the Ni and Zn with different weight fraction Al using ball milling technique. The sample has also been characterized by SEM and EDAX.

II. EXPERIMENTAL

A. Materials and Sample preparation

In the present work the sample mixtures of $Ni_{100-x}Al_x$ and $Zn_{100-x}Al_x$ were prepared by mixing the Ni and Zn with Al in weight ratio $x=10\%$, 20% , 30% , 40% and 50% . The high purity (99.9-99.99 %) fine powder of Al, Ni and Zn were obtained from Sigma Aldrich. The mixing has been done using ball milling (Planetary Ball Mill PM100) contained stainless steel container (volume about 75 cm^3) and stainless steel ball having a diameter of 10 mm. We put the sample powder ($Ni_{100-x}Al_x$ and $Zn_{100-x}Al_x$) separately in ball milling container with ball to powder ratio 10:1 in argon atmosphere. The rotation speed of mill was 250 rpm and milling time, followed by 4hr further grinding with postal mortar.

B. Characterization

The mass attenuation coefficients were determined by measuring of X-rays fluorescent emitted through sample mixture of known thickness. The experimental arrangement is shown in Fig. 1.

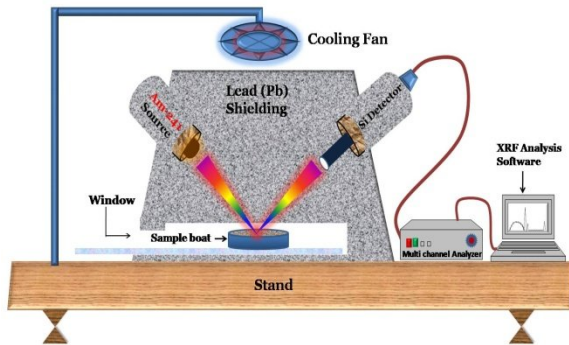


Fig. 1 The experimental setup

The sample mixtures were irradiated with 59.6 KeV X-rays obtained from the 241Am (40 mCi) annular source. The emitted K-line X-rays fluorescents were collimated by the lead collimator shielded with aluminum and iron to fall on samples. These sample mixture was put in circular ring having various thicknesses (1.2-1.5) mg/cm^2 . The X-rays fluorescent was recorded with help of silicon drift detector (SDD) connected to the Fast Comtech multi channel analyzer card. The distance between sample to source was 15mm same as the distance between sample to detector with an angle 90° as shown in Fig.1.

Total mass attenuation coefficient, μ_m (cm^2/g) of mixtures were calculated by Equation (4).

$$\mu_m = \frac{-1}{t} \ln \left(\frac{I}{I_0} \right) \quad (4)$$

Where t (mg/cm^2) is the thickness of sample, I and I_0 are area under the peak (K_α and K_β) for the mixture and pure elements (i.e. Ni, Zn) respectively. The μ_m values obtained experimentally was compared with the theoretical values obtained by Xcom software [21]. The relative difference (RD) between the experimental and theoretical values has been calculated by Equation (5).

$$RD = \frac{(\mu_m)_{exp} - (\mu_m)_{theory}}{(\mu_m)_{theory}} * 100\% \quad (5)$$

The samples have also been characterized using Scanning Electron Microscopy (Zeiss, Germany) and EDAX analysis.

III. RESULT AND DISCUSSION

A. Mass attenuation coefficient (μ_m)

The Fig.2and Fig.3 show the XRF measurements for pure Ni and pure Zn with different weight ratio of Al (10%, 20%, 30%, 40% and 50%). These figures clearly indicate the K_α and K_β X-ray energy peaks for pure Ni and pure Zn have been appeared at 7.47 KeV , 8.26 KeV and 8.63 KeV, 9.57 KeV respectively with higher Intensity.

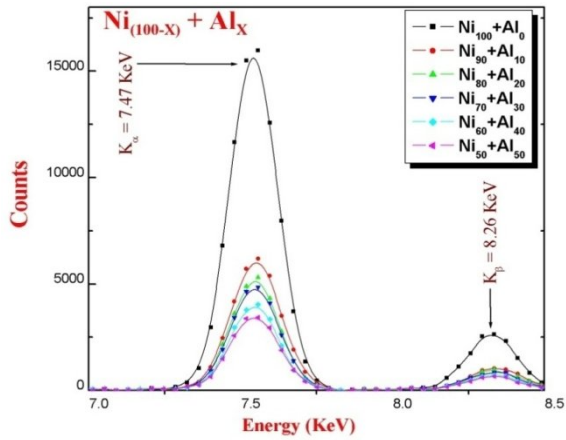


Fig. 2 X-ray fluorescence plots for $Ni_{100-x}Al_x$ mixtures.

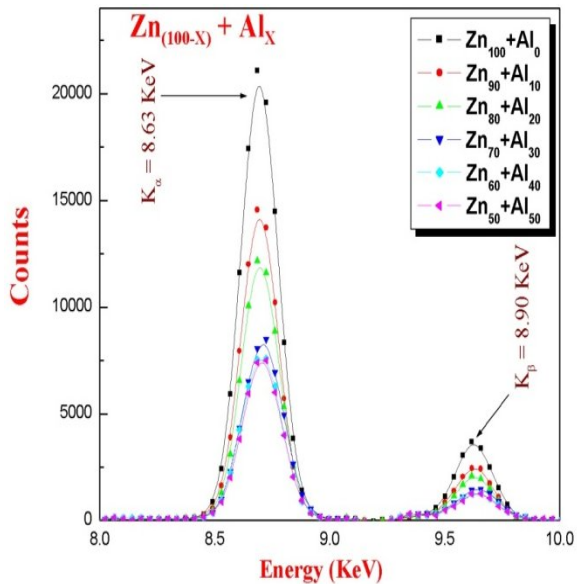


Fig. 3 X-ray fluorescence plots for $Zn_{100-x}Al_x$ mixtures.

It was observed that for mixture samples intensity of the K_α and K_β X-ray energy peaks was decreased as the concentration of Al increased in both Zn and Ni. Mass attenuation coefficient (μ_m) for these mixtures were calculated and it was observed that in case of $Ni_{100-x}Al_x$ the μ_m is linearly increased as the Al concentration increased in Ni mixture while for $Zn_{100-x}Al_x$ the μ_m decreased as the Al concentration increased. The experimental and theoretical plots of μ_m with Al concentration for Ni and Zn mixtures have been shown in Fig. 4

and Fig. 5 respectively. These measured experimental values of μ_m have been compared with theoretical values by Xcom software and have good agreement.

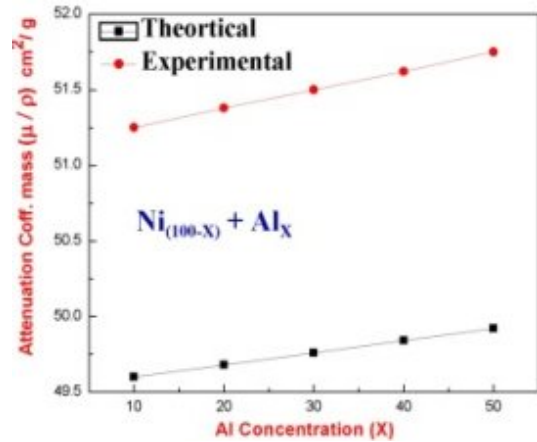


Fig. 4 experimental and theoretical plot between mass attenuation coefficient (μ_m) and Al concentration for $Ni_{100-x}Al_x$ mixtures.

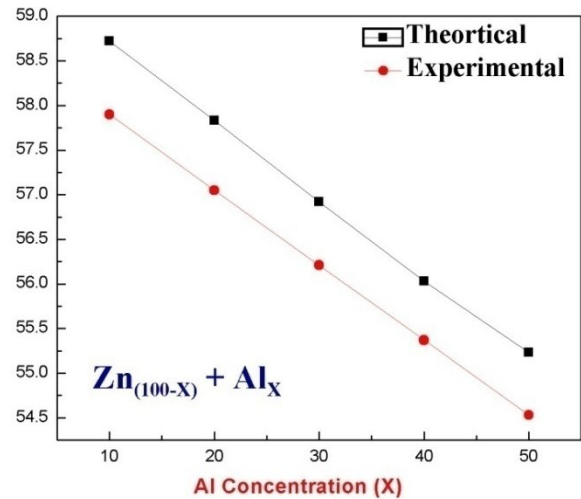


Fig. 5 shows the experimental and theoretical plot between mass attenuation coefficient (μ_m) and Al concentration for $Zn_{100-x}Al_x$ mixtures.

Mass attenuation coefficients (μ_m) in mixtures of Ni increased with Al concentration increased because the density of mixture is high. The μ_m for Zn mixtures was decreased with increased Al concentration, this refers to lower density of $Zn_{100-x}Al_x$ mixtures. The μ_m coefficients of Zn mixtures was higher than mixtures of Ni because

of Zn and their mixtures have higher K_{α} and K_{β} X-ray energy as well as higher atomic number in comparison to that of Ni.

B. Scanning electron microscopy (SEM)

The Fig. 6 and Fig. 7 show the SEM images for $Ni_{50}Al_{50}$ and $Zn_{50}Al_{50}$ mixtures. These images show that mixtures composed of the uniformly distributed uneven granular structure. The EDAX measurement confirms the elemental composition of $Ni_{50}Al_{50}$ and $Zn_{50}Al_{50}$ mixtures.

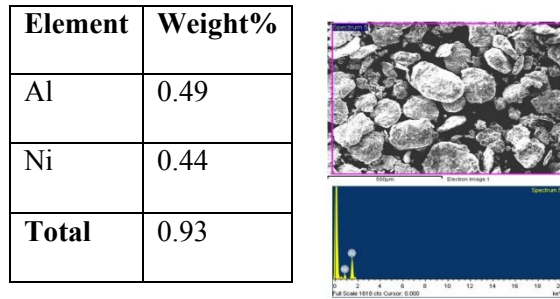


Fig. 6 The SEM image with EDAX analysis for $Ni_{50}Al_{50}$ mixture.

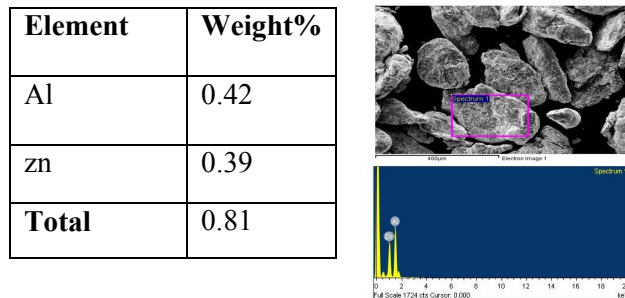


Fig. 7 The SEM image with EDAX analysis for $Zn_{50}Al_{50}$ mixture.

IV. CONCLUSION

The $Ni_{100-x}Al_x$ and $Zn_{100-x}Al_x$ mixtures with different weight ratios of Al ($x = 10-50$) were prepared by mixing method using ball milling technique. The mass attenuation coefficients (μ_m) were measured by self attenuation of characteristics X-rays using XRF technique. It was observed that mass attenuation coefficient (μ_m) for $Ni_{100-x}Al_x$ is linearly increased as the Al concentration increased in Ni mixture while

for $Zn_{100-x}Al_x$ the μ_m decreased as the Al concentration increased. The measured experimental values of μ_m have been compared with theoretical values by Xcom software and have good agreement.

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