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Use of Fuzzy Logic Modelling for Radiation Shielding Properties of Borided Fe-Ni Binary Alloys

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Abstract: In this paper, the radiation shielding properties of borided Fe-Ni binary alloys (Ni-60 wt.% and Ni-80 wt.%) as a function of boronizing parameters (time and temperature) have been investigated by using the fuzzy logic model. For this purpose, the linear attenuation coefficients of borided samples were calculated and fuzzy logic approach was applied to these values. The results showed that fuzzy logic approach can be used to predict the radiation shielding properties of borided Fe-Ni alloys for untested conditions.

***Key words**:* Fuzzy logic model, Boriding, Radiation shielding, Binary alloys

Borlanmış Fe-Ni İkili Alaşımlarının Radyasyon Koruma Özellikleri için Bulanık Mantık Modelinin Kullanımı

Özet: Bu çalışmada, bulanık mantık modeli kullanılarak ağırlıkça % 60 Ni ve %80 Ni içeren borlanmış Fe-Ni ikili alaşımların radyasyon koruma özellikleri borlama parametreleri olan sıcaklık ve zamanın fonksiyonu olarak incelenmiştir. Bunun için, borlanmış numunelerin doğrusal zayıflama katsayıları hesaplanmış ve bu değerlere bulanık mantık modeli uygulanmıştır. Elde edilen sonuçlar, bulanık mantık modelinin test edilmemiş şartlar içinde bile borlanmış Fe-Ni alaşımlarının radyasyon koruma özelliklerini tahmin etmek için kullanılabileceğini göstermektedir.

***Anahtar kelimeler*:** Bulanık mantık modeli, Borlama, Radyasyon koruması, İkili alaşımlar

1. Introduction

Fuzzy set was proposed by Prof. Lofti Zadeh [1] in 1965 that provides an appropriate tool for modelling of imprecise, uncertain and ambiguous phenomenon [2]. Therefore, there is a wide range of applications on some physical, engineering and agricultural problems in the literature. Corresponding to this, Fuzzy Logic Modeling (FLM) has been used to predict the surface roughness, to control the cutting force in various machining processes and estimation, and to prediction in switched reluctance motor

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drives by Celik et.al. [3], Cheok and N. Ertugrul [4], respectively. On the other hand, Vijayaraghavan and Jayalakshmi [5] showed that FLM are used in chemical process systems without any mathematical ambiguity in process industries. In addition, Abiyev et al. [6] successfully applied to FLM to proof process in bread making and to calculate the qualitative values of the risk level. The obtained result has been showed that by using FLM, the robust and reliable estimation is obtained, thus, it is suitable for a wide range of systems.

FLM can stimulate the interpretation phase in determination of radiation protection materials. The goal of this study is to predict the radiation shielding properties of borided Fe-Ni alloys for untested conditions by FLM and, to compare with the recorded measured values at some photon energy levels.

2. Material and Method

2.1 Fuzzy Logic Approach

When we use objective function, design variables and constraints in vague and linguistic terms, we can apply FLM in order to model the relation between the inputs and the outputs.

Throughout this study, $\mathbb{R}^n$ denotes the n-dimensional Euclidean space and $F(\mathbb{R}^n)$ denotes the set of all fuzzy subsets on $\mathbb{R}^n$. If $u \in F(\mathbb{R}^n), r \in (0,1]$, then we write $[u]^r = \{x \in \mathbb{R}^n\ u(x) \geq r\}$.

E^n is said to be a fuzzy number space if $E^n = \{u : \mathbb{R}^n \to [0,1] : u$ satisfies the following conditions $\}$:

- u is normal, i.e., $\exists\, x_0 \in \mathbb{R}^n$ such that $u(x_0) = 1$;
- u is a fuzzy convex set, i.e., $u(rx + (1-r)y) \geq \min\big(u(x), u(y)\big), x, y \in \mathbb{R}^n, r \in [0,1]$;
- u is upper semi-continuous;
- $[u]^0 = \overline{\{x \in \mathbb{R}^n : u(x) > 0\}}\ is\ compact, for\ 0 < r \leq 1, denote\ [u]^r = \{x : x \in \mathbb{R}^n\ and\ u(x) \geq r\}, [u]^0 = \overline{\cup_{r\in[0,1]}\ [u]^r}$.

Then, u is called a fuzzy number [7]. It is clear that each $u \in \mathbb{R}^n$ can be defined as a fuzzy number as

$$u(x) = \begin{cases} 1, & x = u \\ 0, & \text{otherwise.} \end{cases}$$

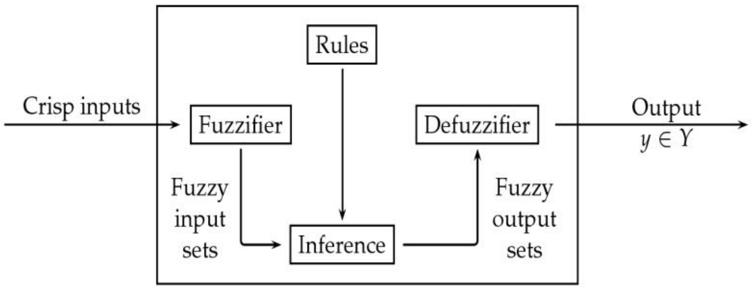

Figure 1. Fundamental elements of FLM.

Each FIS consists of three main phases:

Fuzzification phase. We transform the numerical values of input and output variables into the linguistic terms. Among several types of membership functions we prefer triangular, and trapezoidal membership functions. These membership functions are defined by location of the vertexes of triangles and trapezoids.

Inference phase. In this phase, the logical rule-base is determined. The rule-base is formed conditional expressions as 'If ... then ...'. The number of these rules may change from problem to problem and from model to model.

Defuzzification phase. In this last phase, the fuzzy numbers turn into numerical values. To achieve that, different types of methods such as centroid, middle of maximum, largest of maximum, bisector and smallest of maximum can be used. We prefer centroid method which is presented in [8-11]. Figure 1 shows basic construction of FLM.

2.2 Radiation Shielding

Carbon steels or stainless steels, as lead (Pb), have been commonly used as materials for thermal and radiation shielding [12-15]. Recently, in order to increase the shielding properties, it is intended to use boron together with the steels. In relation to this, studies on borided AISI 316L and micro-alloyed stainless steels show that these materials are used as radiation shielding material [16,17].

In this study, Fe-Ni binary alloys (wt. % 60 and % 80 Ni) were borided in an electrical resistance furnace for exposure times of 2, 4, 6 and 8 h at 1223 K in the temperature range 1073–1373 K for 5h under atmospheric pressure. To investigate the radiation shielding properties of the borided steels, the The linear attenuation coefficient (μ) was measured at some the photon energy (662, 1173 and 1332 keV, respectively). The μ which is the probability of a radiation interacting with a matter was calculated for all samples. Detailed information on radiation measurements and calculation of μ has been given from [18].

3. Results

3.1 Linear Attenuation Coefficients Calculation for Fe-Ni Binary Alloys

In this study, the μ for Fe-Ni binary alloys (wt. % 60 and % 80 Ni) was calculated as a function of photon energies and boriding parameters (temperature and time). The results displayed in Figure 2.

It can be seen from Fig. 2 that the μ values depend on the photon energy and decrease with increasing photon energy. In addition, from this figure, it is clear that the μ is decreasing rapidly at low energy but in high energy it decreases slowly for borided binary alloys at the same time and temperature due to the energy dependence of photon interaction with material. On the other hand, it can be noticed that the μ for borided binary alloys is higher than that for unborided binary alloys. And also, it increases with the increasing boriding time and temperature. This result has been explained with the boride layer thicknesses and boride phases at the borided binary alloys.

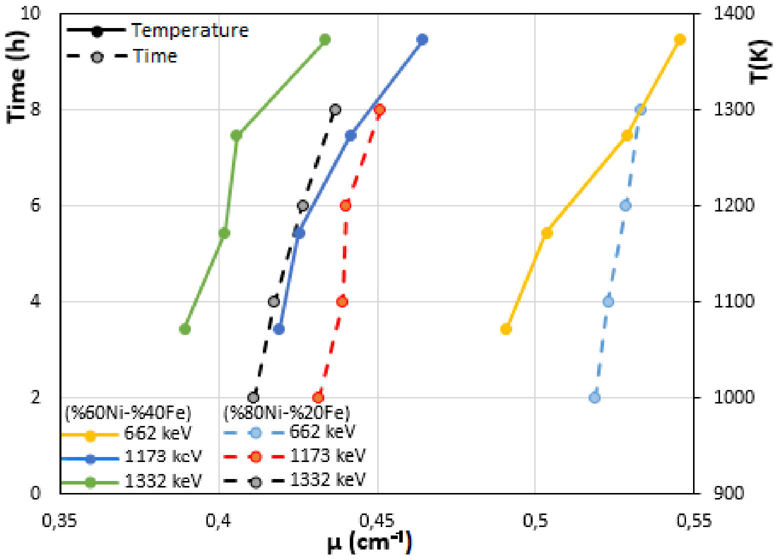

Figure 2. Measured linear attenuation coefficients of the Fe-Ni binary alloys (Ni–60 wt.% and Ni–80 wt.%) as a function of photon energy, boriding temperature and time.

3.2 Applicaiton of Fuzzy Logic Approach

We have constructed the attenuation coefficient of Fe-Ni binary alloys in terms of both boriding temperature and boriding time. The first fuzzy inference system (FIS) is related to the coefficient of temperature, while the second is related to time.

First of all, we have constructed FIS on boriding temperature. Our inputs in this study for first FIS are *Photon Energy Value* and *Boriding Temperature* are input variables. The output is the attenuation coefficient of Fe-Ni binary alloys with respect to the *Photon Energy Value* and *Temperature*.

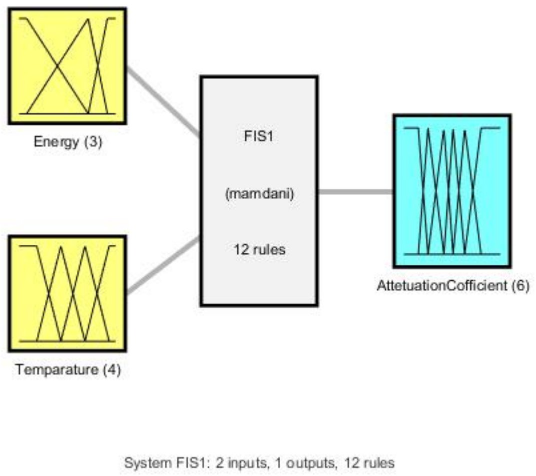

Figure 3. Membership functions for the first FIS.

The membership functions of the photon energy value, temperature and the attenuation coefficient of Fe-Ni binary alloys are given Figure 5-6, respectively. By using FLM approach, we have obtained an estimation for the attenuation coefficient of Fe-Ni binary alloys. Firstly, FLM is used in order to construct a Mamdani type model for the estimation of the attenuation coefficient of Fe-Ni binary alloys on the different boriding temperature and photon energy. The structure of the FIS is presented in Figure 3. The first input range is between 660-1400 while the second input value is between 1000-1400.

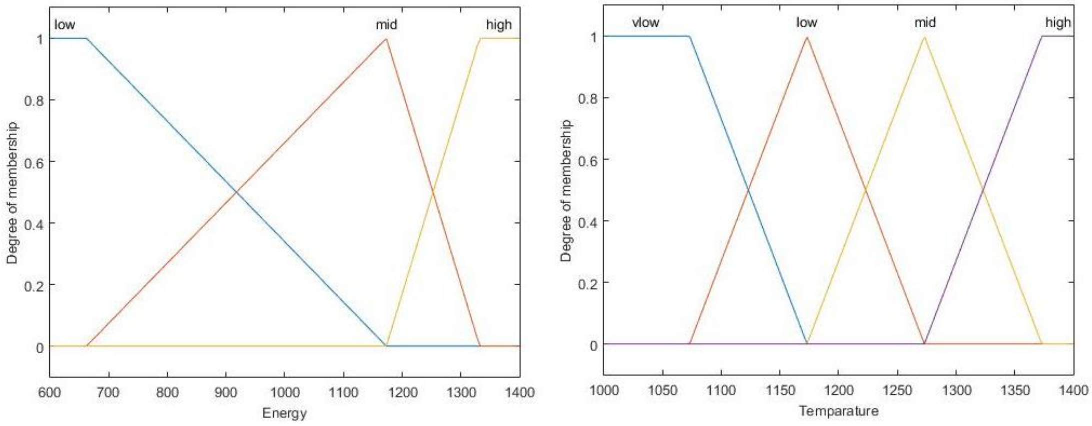

Figure 4. Membership functions of the input variables.

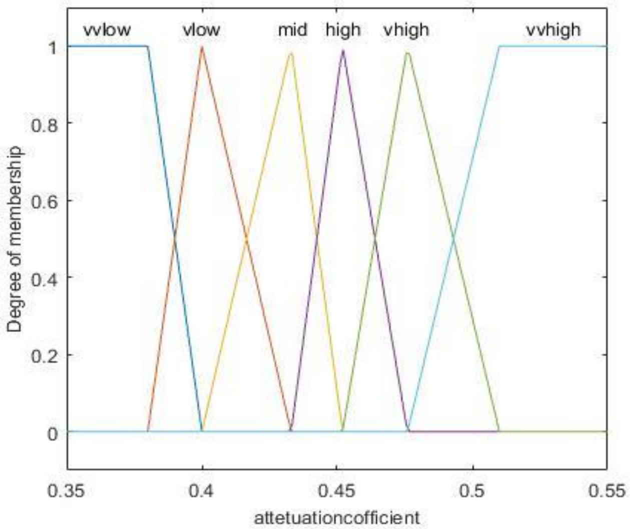

Figure 5. Membership functions of the attenuation coefficient of Fe-Ni binary alloys.

So, we have three and four fuzzy numbers for the boriding energy and temperature, respectively. The first boriding energy (low, mid, high) and the second temperature values (vlow ,..., high) are selected as the input data and, the attetuation coefficient values of the Fe-Ni binary alloys (vvlow,vlow,...,vvhigh) are selected as the output data in our first FIS.

The rule-base is determined in accordance with the valuable interpretations of the experts [1,2]. The elements of the rule-base are as the following:

- If (Photon Energy is low) and (Boriding temperature is vlow) then (Attenuation Coefficient is vvlow) (1)
- If (Photon Energy is low) and (Boriding temperature is low) then (Attenuation Coefficient is low) (2)
- If (Photon Energy is high) and (Boriding temperature is mid) then (Attenuation Coefficient is vvhigh) (3)
- If (Photon Energy is high) and (Boriding temperature is mid) then (Attenuation Coefficient is vhigh) (1)

The surfaces of the attenuation coefficient values of the Fe-Ni binary alloys as a function of photon energy and boriding temperature which is obtained by using centroid method in defuzzification phase is presented in Figure 6.

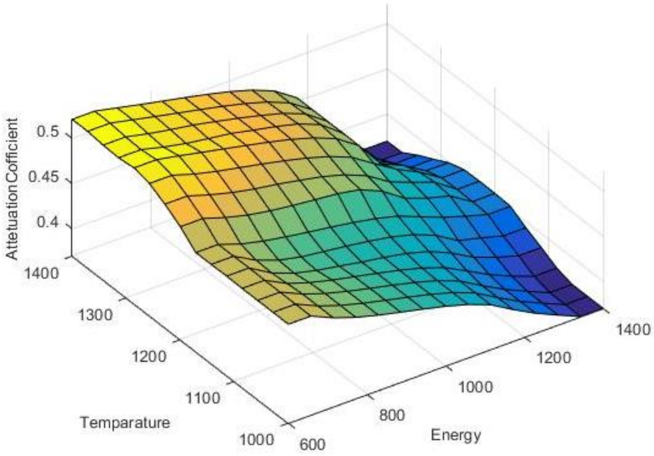

Figure 6. The surface of FIS defuzzified by centroid method.

In engineering problems including experimental data discontinuity is the main problem inherently. So, to make the data continuous as much as possible we establish FLM which estimates the attenuation coefficient values of the Fe-Ni binary alloys for the untested conditions.

In the wake of first FIS, we have constructed second FIS. Similarly, our inputs in this study for second FIS are *Photon Energy Value* and *Boriding time*. The output is the attenuation coefficient of Fe-Ni binary alloys with respect to the *Photon Energy Value* and *Boriding time*.

The membership functions of the photon energy value, boriding time and the attenuation coefficient of Fe-Ni binary alloys are given Figure 10-11, respectively. By using FLM approach, we have obtained an estimation for the attenuation coefficient of Fe-Ni binary alloys. Firstly, FLM is used to construct a Mamdani type model for the estimation of the attenuation coefficient of Fe-Ni binary alloys on the different boriding time and photon energy. The FLM modeling of our problem is shown in Figure 7.

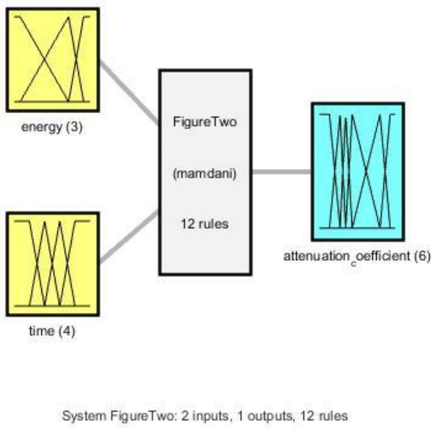

Figure 7. Membership functions for the second FIS.

The first input range is between 660-1400 while the second input value are between 0-10.

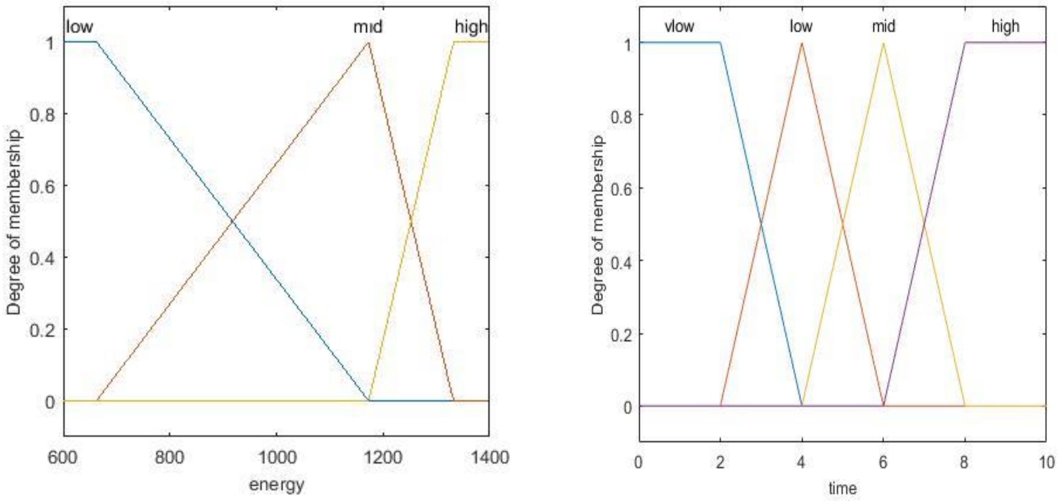

Figure 8. Membership functions of the input variables.

So, we have three and four fuzzy numbers for the boriding energy and time, respectively. The first boriding energy (low, mid, high) and the second temperature values (vlow ,.., high) are selected as the input data and, the attetuation coefficient values of the Fe-Ni binary alloys (vlow,vlow,...,vvhigh) are selected as the output data in our first FIS.

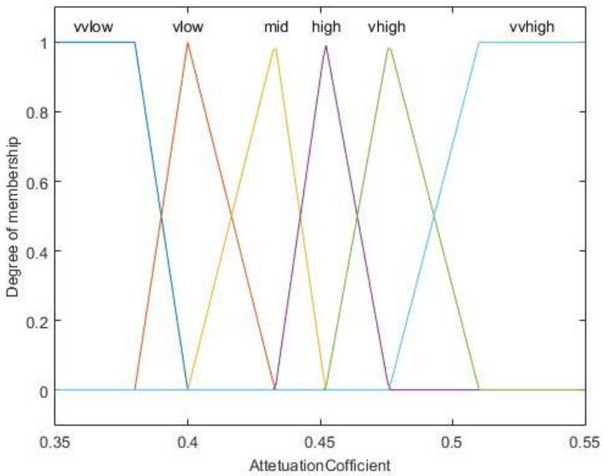

Figure 9. Membership functions of the output variable.

The surfaces of the attenuation coefficient values of the Fe-Ni binary alloys as a function of photon energy and boriding temperature that are achieved by using bisector method in defuzzification stage is represented in Figure 10.

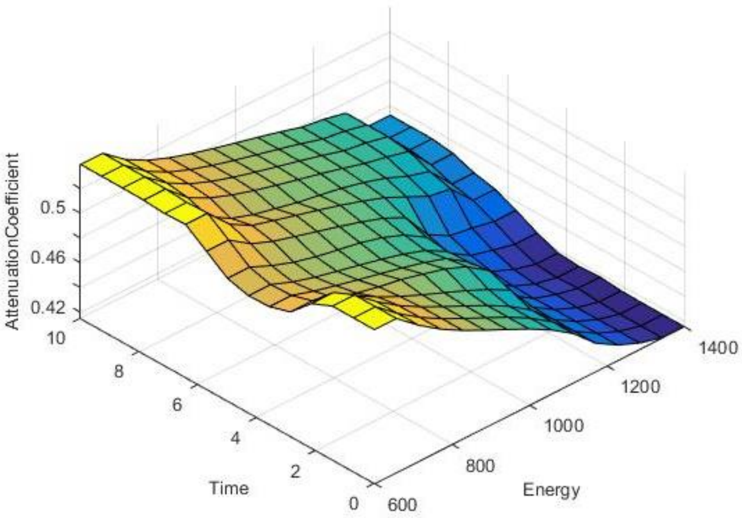

Figure 10. The surface of FIS defuzzified by centroid method.

4. Conclusions and Comment

In this article, FLM has been employed to determine the attenuation coefficient values of the Fe-Ni binary alloys depending on the photon energy, boriding temperature and boriding time and, the results have been compared with the experimental results. Beside, we aimed to get the results for the untested data making the data continuous. In comparison with the results obtained by the physical test, our results are very promising by 96% and 97% consistency rate based on the R^2 value (Figure 11). On the other hand, we have observed that the maximum attenuation coefficient value can be obtained at some input variables (photon energy, boriding temperature and boriding time) such that the other tests may not catch these points.

Clearly, this study will lead many kinds of physical and engineering problems. So, the FLM method can be utilized together with traditional and non-traditional techniques and the obtained results can be compared with each other.

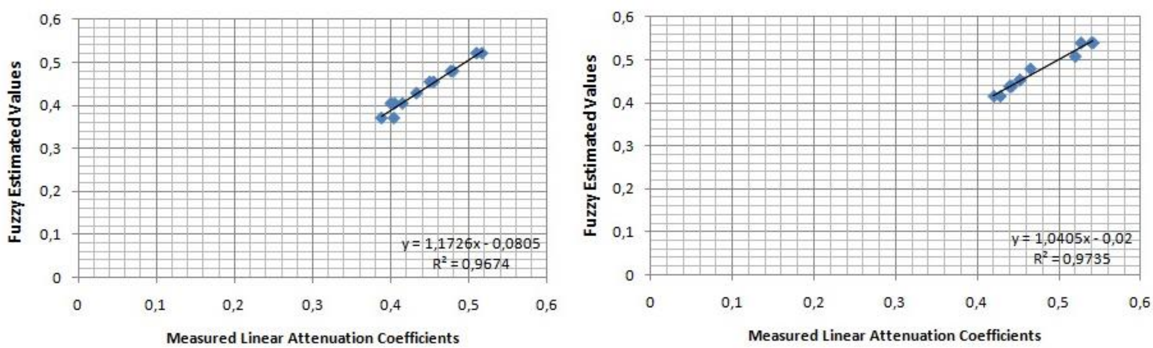

Figure 11. Comparisons of the physical tests and Mamdani type FLM predictions.

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