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# A multi-criteria decision analysis (MCDA) for materials selection of a magnetic application

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**Abstract**

The choice of materials for a manufacturing enterprise is important. An improper selection can negatively affect productivity, profitability and undermine the reputation of an enterprise or policy because of the growing demands for extended producer responsibility.
Ecuador has been conducted to quantify the benefits of implementing induction cookers by the "efficient cooking plan". To make the selection of materials for induction cookware, must take into account the interplay between the requirements of design, material and processing.
This investigation shows results about materials selection for induction cookers which takes into account the interplay between the requirements of design, materials and product processing. It has identified physical properties, as well as, restrictions on the health, appearance, material and processing cost. Finally, it has studied the ability to adapt manufacturing processes by industry in Ecuador. As a result, it has established the candidate materials which meet the above requirements.

**Keywords.** cooker, cookware, materials selection, multicriteria analysis, multi-criteria decision analysis (MCDA), ferromagnetic application.

## Un análisis de decisión multicriterio (MCDA) para selección de materiales de una aplicación magnética

**Resumen**

La elección de los materiales para la fabricación de un producto es importante. Una selección inadecuada puede afectar negativamente a la productividad, la rentabilidad y desprestigiar la reputación de una empresa o gobierno debido a las crecientes demandas de responsabilidad al productor. Ecuador está llevando a cabo la implementación cocinas de inducción por el "plan de cocción eficiente". Para hacer la selección de los materiales para los utensilios de cocina de inducción, se debe tener en cuenta la interacción entre los requisitos de diseño, material y procesamiento.
Esta investigación muestra resultados sobre la selección de materiales para cocinas de inducción, que tiene en cuenta la interacción entre los requisitos de diseño, materiales y transformación de los productos. Se ha identificado las propiedades físicas, así como, las restricciones sobre el costo de la salud, la apariencia, el material y el procesamiento. Finalmente, se ha estudiado la posibilidad de adaptar los procesos de fabricación de la industria en el Ecuador. Como resultado, se ha establecido los materiales candidatos que cumplen los requisitos anteriores.

**Palabras Clave.** menaje, cocinas de inducción, método multicriterio para la selección de materiales.

## Introduction

Induction cookers are devices that enhance the life quality of a society, improving the human development index (HDI), the Multidimensional Poverty Index (MPI), the welfare of the society and energy efficiency of the energy system [1]. In case of Ecuador the introduction of induction cookers in society is related to the objectives of welfare, and improves the quality of life of its population joined to the "efficient cooking plan" [2].

In the particular case of the energy system of Ecuador have been conducted to quantify the benefits of implementing induction cookers by the "efficient cooking plan" [3, 4]. It has been observed that if the state remove subsidy to LGP cookers and inserts a total subsidy for the first 100 kWh for induction cookers in the program, the state would save US $ 260.7 million annually from data of 2012.

Induction cooking heats a cooking cookware by magnetic induction, instead of thermal conduction from a flame, or an electrical heating element. The cooking cookware must contain a ferromagnetic metal such as cast iron or stainless steel in its base. Copper, glass and

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aluminum pots can be placed on a ferromagnetic interface disk which functions as a conventional hotplate.

Induction cooking heats a cooking vessel by magnetic induction, instead of by thermal conduction from a flame, or an electrical heating element. For nearly all models of induction cooktops, a cooking vessel must be made of or contain a ferromagnetic metal such as cast iron or stainless steel. Copper, glass and aluminum vessels can be placed on a ferromagnetic interface disk which functions as a conventional hotplate.

In an induction cooker, a coil of copper wire is placed under the cooking pot and an alternating electric current is passed through it. The resulting oscillating magnetic field induces a magnetic flux which repeatedly magnetises the pot, treating it like a lossy magnetic core of a transformer. This produces large eddy currents in the ferrous pot, which because of the resistance of the pot, heats it [5].

Induction cooker has a few advantages when compared with traditional cooker. There are two major advantages of the induction cooker, namely, energy saving and safety enhancement. The safety functions of induction cooker include:

- No further power output when cookware is removed from the hob.
- It has automatically cut–off function in case of overheating.
- No radiated heat and unnecessary heating of the room from the hot cooking range.
- Free from naked flame and smoke.
- Reduce the risk of burn and ignition of spilled fat or oil.
- No emission of harmful gas

Cooking food by induction has many advantages over traditional systems which include the following features:

- Increased energy efficiency, the magnetic field induced in the pot and the absence of high temperature in heaters reduces heat loss to the environment.
- The speed of the heating due to the ferromagnetic material of the base of the cookware has the ability to attract and pass through them magnetic fields, as soon as electricity flows through the coil, which causes the warm pot directly and not the surface.
- Increased safety, there is no risk of burns in the kitchen, or explosions, because no flame is produced.
- Improved ease of cleaning, by having a smooth surface.
- Easy to operate with digital controls.

The main disadvantages are:

- More sophisticated than the electrical resistance and LGP cookers.
- Be careful when using it, to avoid scratching the hob.
- Induction cookers of several zones have a high price.

To make the selection of materials for induction pots, must take into account the interplay between the requirements of design, material and processing. For example, you should not make the selection of a material having the best characteristics in terms of heating rate, if after manufacturers of furniture of Ecuador cannot access the material or sufficient infrastructure for processing, or the material may have potential health risks. That is why the selection of materials for household kitchens induction is a complex subject, so that the use of different models of selection of materials like Scoring, Standard (01-Z) and Pres methods, you choose the best materials for the process [6–8].

## Materials and Methods

For a material selection for an industrial application, the first step is to identify the requirements in the design. This requires identifying the function or purpose of the system which is designed. In this case it is the cookware for an induction cooker, and you want to determine what type of cookware has the best cost-benefit ratio, defined as the benefit from material the energy efficiency of the system cookware-cooker during cooking. This idea will impact on a lower energy consumption and higher thermal inertia (or heating rate) of cookware. As a consequence it will be necessary a shorter time during cooking.

Next, it will be essential to identify and present the explanation, to have a good understanding of physical phenomena and to assess which are the most important physical properties. In the case of the pots for induction cookers it will be very important, the magnetic permeability, conductivity and the workability of the material, as discussed in the following section.

In addition, it is very important restrictions on the design constraints such as health, cost of material and analyze whether the domestic industry can adapt their manufacturing processes to this type of cookware will be considered.

Finally there will be a selection of materials with matrices, Scoring, Press and Standard (01-Z) methods procedures, depending on the method of selection, will be a qualitative or quantitative method and take into account or not significant factors in the selection criteria. The selection is done with matrices, in the ranks criteria and weighting factors are included [7, 8].

**Principle of operation**

When the induction cooker is activated an induced current circulates by the wire which heats the material. When the material is heated, the heat is dissipated by the Joule effect.

The power dissipated by Joule effect as a result of the induced currents or Foulcalt often simplified in the formula P=R·$i^2$, but in this case cannot be applied directly for the current distribution is not uniform. For a nonuniform current distribution is fulfilled [9]:

$$P = \pi \cdot d \cdot h \cdot H^2 \cdot \sqrt{\frac{\pi \cdot \mu \cdot f}{\sigma}} \cdot C \cdot F \qquad (1)$$

*d = cylinder diameter (m).*
*h = cylinder height (m).*
*H = magnetic field strength (A/m).*
$\sigma$ *= electric conductivity (S/m).*
$\mu$ *= permeability of the material (H/m).*
*f = frecuency (Hz).*
*C = coupling factor.*
*F= power transmission factor.*

*F* and *C* are correction factors which depend on the geometry of the load and the distance between the inductor and the load. As a result of the formula have the following conclusions:

The material characteristics are very important, especially the relative permeability $\mu$ and $\sigma$ the electrical conductivity. Ferromagnetic materials exhibit these features and help maximize power transfer at high temperatures in the load with low losses at the source. Shows how the pieces of material characteristics are very important as the diameter *d* and height *h*.

**Physics properties**

- Magnetic permeability: It is the ability of a substance or means to attract and passing through it magnetic fields. The degree of magnetization of a material in response to a magnetic field is called absolute permeability and is usually represented by the symbol $\mu$.

  $$\mu = \frac{B}{H} \qquad (2)$$

  *B = magnetic induction into the material.*
  *H = magnetic field strength into the material.*

  To compare together the materials, means the absolute magnetic permeability $\mu$ as:

  $$\mu = \mu_r \mu_o \qquad (3)$$

  $\mu_r$ *= relative permeability.*
  $\mu_o$ *= vacuum permeability.*

  The permeability values for different materials typically used in pots shown in Table I.

- Electrical conductivity: It is the ability of a material to allow electrical charges move freely. The conductivity depends on the atomic and molecular structure of the material. Metals are good conductors because they have a structure with many free electrons due to the metallic bond or electron cloud that allows movement. The conductivity is also dependent on other physical factors of the material and the temperature.

  Values of thermal conductivity for various materials commonly used in pots are shown in Table I. In formula (1) is showed that the electrical conductivity worse the energy efficiency, so it will be interesting to have materials with lower electrical conductivity than steels.

- Thermal conductivity: It is the ease with which the material absorbs and transmits energy. A higher the thermal conductivity of the material will heat up and expand to unheated areas of the same piece of material.

  Values of thermal conductivity for various materials commonly used in cookware are shown in Table I. Shows that there is a relationship between electrical and thermal conductivity of the materials, due to the crystalline structure of the materials.

- Specific heat capacity or specific heat: It is the amount of internal kinetic energy stored in a material. The molecular composition of materials makes the molecular kinetic energy increases with varying difficulty and molecular potential energy stored more or less difficulty.

  The cookware made of materials with high specific heat capacity, need more time to warm up, but also have a significant amount of stored energy when they are hot and the material temperature decrease more slowly when their energy is transferred.

  The heat capacity and thermal capacity of a material is proportional to its mass, so a piece of cookware with more mass has greater thermal capacity, so that the density must be known to make comparisons between different cookware materials.

- Thermal diffusivity: A property that indicates how fast heat is transferred through and out of the material. Thermal conductivity is divided by the unit heat capacity. In Table II the values of thermal diffusivity of the materials typically used in pots are presented; seen as copper and aluminum have an order of magnitude higher than the steel and cast iron.

- Reactivity: It is necessary to ensure that the materials used in the household does not impair or adversely affect the taste of food. It is therefore important to use non-reactive materials. Problems with cooper and aluminium were observed but it is necessary to absorve a high concentration [12–14]

| Material | Relative magnetic permeability $\mu_r$ | Electric conductivity $\sigma_e \cdot 10^7$(S/m) | Thermal conductivity $\sigma_t$ (W/m·K) | Specific heat (J/kg·K) | Density (kg/m$^3$) |
|---|---|---|---|---|---|
| Cooper | 0.999994 | 5.96 | 401 | 390 | 8900 |
| Aluminium | 1.000022 | 3.78 | 237 | 910 | 2600 |
| Austenitic stainless steel (AISI 304 - AISI 316) | 1.003 - 7 | 0.14 | 16 | 460 | 7930 |
| Ferritic stainless steel (AISI 430 - AISI 436) | 1000 - 1800 | 0.15 | 16 | 460 | 7930 |
| Carbon steel | 50 - 150 | 0.70 | 53 | 460 | 7850 |
| Electrical steel (Steel with 1-5% w.t. Si) | 4000 - 5000 | 0.22 | 68 | 460 | 7850 |
| Enameled iron | 500 - 800 | 1.00 | 85 | 460 | 7800 |

**Table 1: Material Properties [10, 11].**

| Material | Thermal diffusivity $10^{-6}$ (m$^2$/s) | Young Modulus E [GPa] | Yield strength $\sigma_y$ [MPa] | Ultimate tensile strength $\sigma_R$ [MPa] | Price ($/T) | Corrosion resistance |
|---|---|---|---|---|---|---|
| Cooper | 80 | 120 | 32 | 210 | 10000 | In the presence of air and water turns green and black |
| Aluminium | 92 | 45 | 17 | 45 | 3500 | Good resistance in air and water[1] |
| Austenitic stainless steel (AISI 304 - AISI 316) | 4 | 190-215 | 380 | 460-1100 | 4500 | Excellent resistance in air and water[1] |
| Ferritic stainless steel (AISI 430 - AISI 436) | 8 | 190-215 | 380 | 460-1100 | 4000 | Good resistance in air and water[1] |
| Carbon steel | 250 | 210 | 200-300 | 750 | 1000 | Corrodes in water and air |
| Electrical steel (Steel with 1-5% w.t. Si) | 15 | 190-210 | 315-500 | 400-1100 | 2500 | Corrodes in water and air |
| Enameled iron | 22 | 210 | 135 | 195 | 500 | Corrodes in water and air |

[1]Weight loss under 25 mg/dm$^2$ during 24 h.
[2]Weight loss under 250 mg/dm$^2$ during 24 h.

**Table 2: Material Properties [10, 11].**

Stainless steel is the least reactive of all popular materials used in cookware.

- Workability: Commonly refers to the ease with which a material can be molded plastic flow without the occurrence of external or internal fractures, or the ability of plastic deformation of the material, above the yield strength without cracking. This concept includes all terms related to operations forming material and ability to be forged, rolled, extruded, drawn and shaped. This parameter can be analyzed in the laboratory by mechanical tests, depending on the application normally used in tensile, compression tests, and torsion tests cupping test. The workability depends on the microstructure of the material, the temperature applied, prior thermal or surface treatments and the strain rate [15].

  It is necessary to consider the stress-strain curve and the important parameters such as yield, its breaking stress and Young's modulus. In Table II is showed the values of Young's modulus material, yield strength, tensile strength and melting temperature of the materials listed.

  Workability is important to consider the production of materials in Ecuador and determine if the household can be made entirely with materials having the country or if instead it will be necessary cookware manufacturers have to import material.

  In the case of steel have been published reports on this subject by the National Institute of Preinversión (INP) [16] and Acelor-Mital Ecuador [17], with similar results. They show that Ecuador is an importer of steel products, which will be necessary for the production of ferromagnetic induction plates to import the material. Ecuador is also a producer of aluminum country, being the origin of imports countries like Argentina, France, Venezuela, USA and Canada (Central Bank of Ecuador).

- Price of materials: The price of the material is a variable that directly affects the price of the user. In Table II is showed the material prices in US $ per ton appear, shown as steel is the cheapest of all of them per ton, however the aluminum is about three times less dense, which makes it competitive.

- Corrosion resistance: The ability of a material to retard spoilage as a result of electrochemical etching by the surrounding environment.

  In Table II the behavior is observed in terms of corrosion resistance of the materials to air, water and oil, however these materials may react with regard to certain acids.

- Appearance: Generally known consumer product features, so that the choice between two products with similar prices usually done for appearance. That is why the final product should have a shiny appearance.

| **Candidate materials for the selection process** |
|---|
| **A**: Enameled iron |
| **B**: Enameled iron with vitrified treatment |
| **C**: Stainless steel AISI 430 or AISI436 |
| **D**: Stainless steel AISI 430 or AISI436 and aluminum |
| **E**: Electrical steel |
| **F**: Electrical steel with nonstick ceramic coating inside and vitrified treatment |
| **G**: Electrical steel and stainless steel AISI 304 or AISI 316 with nonstick ceramic coating inside and vitrified treatment |
| **H**: Electrical Steel, aluminium and nonstick Teflon coating |
| **I**: Stainless steel AISI 430 o AISI436, steel AISI 304 o AISI 316 and nonstick ceramic coating inside |
| **J**: Electrical steel, cooper and vitrified treatment |

**Table 3: Candidate materials for the selection process.**

In Table III candidate materials for the selection process, which have been selected to compare the effect of different materials and different configurations nonstick treatment and corrosion resistance are observed. There are various European and US patents where the nonstick process of cookware and subsequent treatments until it is finished are specified which is included in the price here because it can influence [18–20].

## Results

### Scoring Method

The scoring method is used chose the best options for a material selection. This method involves categorize and quantify the design material and. evaluated based on their importance, which allows for proper selection. This methodology is described in the following steps.

1. Select each criterion for the cookware considering how important it is for the other parameters. The selected scale is between the values 0-1 from least to most important.
2. Set as each alternative is satisfied based on criteria.
3. Scale each criteria between the values 0-10 from least to most important.
4. Calculate the scores for each alternative.
5. After the summation, the alternatives are selected to present the most positive outcome.

In Table IV is shown the weight matrix with the design criteria and the rating for candidate materials. These properties were evaluated for each of the materials scoring method.

### Pres Method

The Pres method aims to determine the most favorable alternative comparing alternatives. It sets the relationship between alternatives for each and every one of the criteria for the study of solutions. Thus the method promulgates the optimal choice in the alternative that is better than the other in the greatest possible number of criteria and is the one with minor weaknesses against the other. It is simple conceptual approach makes it easily replicable and development is as follows:

- Establish specific criteria and weights: $C_i$ and $W_i$.
- Evaluation criteria for each of the alternatives: $x_{ij}$.
- Determination of the matrix.

The values of the weights criteria are normalized.

$$W_j = \frac{W_i}{\sum_{i=1}^{N} W_i} \tag{4}$$

The values of the criteria are normalized.

$$c_j = \frac{c_j}{c_{i\,\max}} \tag{5}$$

In case of a criteria which the best value is the minimum calculation of the $1/c_i$ is made.

After the summation, the alternatives are selected to present the most positive outcome.

In Table V is shown the weight matrix with the design criteria and the rating for candidate materials. These properties were evaluated for each of the materials scoring method.

These properties were evaluated for each of the materials scoring method.

### Standard Method (01-Z)

This method is a simple multi-criteria evaluation, able to identify the relative importance among criteria and integrate a variety of quantitative and qualitative indicators. It is distinguished by the use of a comparison matrix using criteria and statistical tool Z.

The method of calculating the weights is very simple. You must add the rows and calculate what percentage they represent of the total.

| Design criteria | Weight | A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Magnetic permeability** | 1 | 6 | 6 | 8 | 8 | 10 | 10 | 10 | 10 | 8 | 10 |
| **Reactivity** | 0.8 | 1 | 8 | 8 | 10 | 1 | 8 | 8 | 1 | 10 | 10 |
| **Price / Appearance** | 0.9 | 10 | 6 | 1 | 6 | 4 | 1 | 4 | 4 | 8 | 1 |
| **Thermal diffusivity** | 0.5 | 10 | 10 | 6 | 8 | 8 | 8 | 8 | 10 | 8 | 10 |
| **Electric conductivity** | 0.4 | 8 | 8 | 8 | 10 | 8 | 8 | 8 | 10 | 10 | 10 |
| **Corrosion resistance** | 0.4 | 3 | 8 | 6 | 8 | 3 | 8 | 8 | 8 | 8 | 4 |
| **Yield strength $\sigma_{\mathrm{y}}$ (MPa)** | 0.3 | 10 | 10 | 6 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| **Young modulus E (GPa)** | 0.2 | 8 | 8 | 8 | 0.5 | 8 | 8 | 8 | 8 | 8 | 4 |
| **Ultimate tensile strength $\sigma_{\mathrm{R}}$ (MPa)** | 0.2 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 6 | 8 | 4 |
| **Results** | | **32.4** | **36.4** | **28.1** | **37.6** | **28.4** | **33.3** | **36** | **31.8** | **40** | **33.5** |

**Table 4: Evaluation Matrix: Design criteria and values for candidate materials for Scoring Method.**

| Design criteria | Weight criteria normalized | A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Magnetic permeability** | 0.21 | 0.15 | 0.15 | 0.31 | 0.31 | 1 | 1 | 1 | 1 | 0.7 | 1 |
| **Reactivity** | 0.17 | 1 | 1 | 1 | 0.6 | 0.6 | 0.8 | 1 | 1 | 0.8 | 1 |
| **Price / Appearance** | 0.19 | 1 | 0.8 | 0.7 | 0.65 | 0.2 | 0.15 | 0.15 | 0.15 | 0.6 | 0.1 |
| **Thermal diffusivity** | 0.11 | 1 | 1 | 0.36 | 0.48 | 0.68 | 0.68 | 0.68 | 0.68 | 0.36 | 0.68 |
| **Electric conductivity** | 0.09 | 0.18 | 0.18 | 1 | 0.85 | 0.24 | 0.24 | 0.24 | 0.24 | 1 | 0.24 |
| **Corrosion resistance** | 0.09 | 0.5 | 1 | 0.8 | 0.9 | 0.3 | 1 | 1 | 0.5 | 0.8 | 1 |
| **Yield strength $\sigma_{\mathrm{y}}$ (MPa)** | 0.06 | 0.13 | 0.13 | 0.04 | 1 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| **Young modulus E (GPa)** | 0.04 | 1 | 1 | 1 | 0.22 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Ultimate tensile strength $\sigma_{\mathrm{R}}$ (MPa)** | 0.04 | 0.26 | 0.26 | 1 | 0.26 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Results** | | **0.62** | **0.63** | **0.65** | **0.62** | **0.56** | **0.64** | **0.67** | **0.63** | **0.68** | **0.67** |

**Table 5: Evaluation Matrix: Design criteria and values for candidate materials for Pres Method.**

On the other hand, is able to compare the different indicators for material selection in each of its criteria, through the standardization of their values.

Standardization (Z) is a technique that allows the standardization of the measurement scales for the comparability of these. This is possible by means of standardized indicators through measures of central tendency, thus the data are comparable, and it is observed the relative distances of each indicator, collection, average.

This is due to calculate the average and standard deviation of each indicator.

Before it we calculate the values of the criteria are normalized by (4).

The formulas for the mean and standard deviation are:

$$\tilde{x}_j = \frac{\sum x_{i,j}}{n} \tag{6}$$

$$S_j = \sqrt{\frac{\sum \left(x_{i,j} - \tilde{x}_j\right)^2}{n}} \tag{7}$$

Where:

$\tilde{x}_j$: is the media for the j indicator.

$x_{i,j}$: data i for j indicator.

$S_j$: is the standard desviation for j indicator.

| Design criteria | A | B | C | D | E | F | G | H | I | J | Media | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Magnetic permeability | 0.15 | 0.15 | 0.31 | 0.31 | 1 | 1 | 1 | 1 | 0.7 | 1 | 0.52 | 1.34 |
| Reactivity | 1 | 1 | 1 | 0.9 | 0.6 | 0.8 | 1 | 1 | 0.8 | 1 | 0.90 | 0.17 |
| Price / Appearance | 1 | 0.8 | 0.7 | 0.65 | 0.2 | 0.15 | 0.15 | 0.15 | 0.6 | 0.1 | 0.33 | 1.01 |
| Thermal diffusivity | 1 | 1 | 0.36 | 0.48 | 0.68 | 0.68 | 0.68 | 0.68 | 0.36 | 0.68 | 0.62 | 0.45 |
| Electric conductivity | 0.18 | 0.18 | 1 | 0.85 | 0.24 | 0.24 | 0.24 | 0.24 | 1 | 0.24 | 0.31 | 0.94 |
| Corrosion resistance | 0.5 | 1 | 0.8 | 0.9 | 0.3 | 1 | 1 | 0.5 | 0.8 | 1 | 0.73 | 0.60 |
| Yield strength $\sigma_{\mathrm{y}}$ (MPa) | 0.13 | 0.13 | 0.04 | 1 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.07 | 0.81 |
| Young modulus E (GPa) | 1 | 1 | 1 | 0.22 | 1 | 1 | 1 | 1 | 1 | 1 | 0.86 | 0.55 |
| Ultimate tensile strength $\sigma_{\mathrm{R}}$ (MPa) | 0.26 | 0.26 | 1 | 0.06 | 1 | 1 | 1 | 1 | 1 | 1 | 0.54 | 1.33 |

**Table 6: Design criteria and values for candidate materials with normalized values, with media and standard deviation for Standard Method (01-Z).**

| Design criteria | Weight criteria normalized | A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Magnetic permeability | 0.21 | -0.28 | -0.28 | -0.16 | -0.16 | 0.36 | 0.36 | 0.36 | 0.36 | 0.13 | 0.36 |
| Reactivity | 0.17 | 0.6 | 0.6 | 0.6 | 0 | -1.77 | -0.59 | 0.6 | 0.6 | -0.59 | 0.6 |
| Price / Appearance | 0.19 | 0.67 | 0.47 | 0.37 | 0.32 | -0.13 | -0.18 | -0.18 | -0.18 | 0.27 | -0.23 |
| Thermal diffusivity | 0.11 | 0.84 | 0.84 | -0.59 | -0.32 | 0.12 | 0.12 | 0.12 | 0.12 | -0.59 | 0.12 |
| Electric conductivity | 0.09 | -0.14 | -0.14 | 0.58 | 0.45 | -0.09 | -0.09 | -0.09 | -0.09 | 0.58 | -0.09 |
| Corrosion resistance | 0.09 | -0.39 | 0.45 | 0.12 | 0.28 | -0.72 | 0.45 | 0.45 | -0.39 | 0.12 | 0.45 |
| Yield strength $\sigma_{\mathrm{y}}$ (MPa) | 0.06 | 0.07 | 0.07 | -0.04 | 1.15 | -0.04 | -0.04 | -0.04 | -0.04 | -0.04 | -0.04 |
| Young modulus E (GPa) | 0.04 | 0.26 | 0.26 | 0.26 | -1.17 | 0.26 | 0.26 | 0.26 | 0.26 | 0.26 | 0.26 |
| Ultimate tensile strength $\sigma_{\mathrm{R}}$ (MPa) | 0.04 | -0.23 | -0.23 | 0.3 | -0.37 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| **Results** | | **0.22** | **0.26** | **0.16** | **0.07** | **-0.29** | **0.01** | **0.21** | **0.13** | **0.00** | **0.20** |

**Table 7: Design criteria and values for candidate materials and results for normalized values Standard method (01-Z).**

In Table VI is shown the weight matrix with the design criteria and the rating for candidate materials.

Once we have obtained the mean and standard deviation can proceed with the standardization of data. The Z statistic is constructed as follows in (7):

$$Z_{i,j} = \frac{x_{i,j} - \tilde{x}_j}{S_j} \qquad (8)$$

The values of the weights criteria are normalized by (4).

In Table VII is shown the evaluation matrix with the design criteria and the rating for candidate materials. Values are then added and the hierarchy is established.

## Discusion

With the results of the three methods of analysis is observed that the most inclusive method of the three is the Standard Method (01-Z).

The configurations of materials E and H may have corrosion problems utensils prematurely, which is why discarded. This problem could be in the configuration I if instead of AISI 304 steel in the body of cookware is chosen AISI 201 and AISI 202 steel.

In the case of material C configuration, this is not a material that easily to work, which can generate high production costs.

The configuration of material G and J could be the setting for the most promising material for cookware. However its production process would be more expensive due to stamping or welding to join the two steels and the vitrified process.

The enameled cast iron with vitrification treatment present better results than the material unglazed. This generally occurs in each of the materials, since better results against corrosion and reactivity.

## Conclusions

The material having the best results for the Scoring and Pres methods is the material I. In case of Standard Method (01-Z) the best results were presented in B configuration it is due to the good thermal diffusivity of the material.

Usual pot configuration like B and D obtain positive results, but D need higher pressure release in the production process would be necessary to stamp the steel disc at the bottom of aluminum.

It is preferable to have a ceramic non-stick coating in case of Teflon or aluminum as it may incur a health problem and the deformation of the pan. Although it increases about 15-20% nonstick painting process.

Depending on the users are going to cook food with water or frying with oil, it will be easier or more complicated than food, which some requirements will be needed as more or less ambitious reactivity and thus a nonstick coating adhere.

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