

# The Study of Complex (Ti, Zr, Cs) Nanopowder Influencing the Effective Ionization Potential of Arc Discharge When Mma Welding

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**Abstract.** Strength is one of the most important characteristics of a weld joint. Mechanical properties of a weld metal can be improved in a variety of ways. One of the possibilities is to add a nanopowder to the weld metal. Authors of the paper suggest changing the production process of MMA welding electrodes via adding nanopowder Ti, Zr, Cs to electrode components through liquid glass. Theoretical research into the nanopowder influence on the effective ionization potential ( $U_{eff}$ ) of welding arc discharge is also necessitated. These measures support arcing stability, improve strength of a weld joint, as the consequence, ensure quality enhancing of a weld joint and the structure on the whole.

## Introduction

The 21<sup>st</sup> century is distinguished by the breakthroughs in development of nano-materials and nanotechnologies. Apparently, technological advance can hardly be ensured via using and combining conventional materials, as well as better understanding their functions is impossible without nano-materials. Sciences and technologies, studying nano-materials, provide unique opportunities for development of future-oriented combinations of materials [1]. Up to date technologies are used in the most important spheres of human activities (industry, defense, radio-electronics, health care system, power engineering, information systems, transport, biotechnology) for manufacturing solar batteries, superconductors, composite and ceramic materials, magnet and colouring pigments, solders, additives to lubricants etc.

At present, technologies enhancing the quality of metalware, resisting to maximal operational loads, are in focus of engineers and researchers. In welding production strength is one of the most important characteristics of a weld joint [2].

The purpose of applying the nanopowders is to achieve a fine-grain structure of a weld metal without any influence on chemical composition of an alloy; these additives cause grain refinement under crystallization, as the result, mechanical properties are improved. It is also perspective to use nano-materials to stabilize arc discharge when fusion welding.

Electric welding arc is a stable and longtime electrical discharge, arising in the atmosphere between hard and liquid electrodes, provided that current density is high, and followed by considerable heat release. Electric discharge in the atmosphere is electric current, flowing through it due to free



electrons, and negative and positive ions movable among electrodes under the action of an applied electric field (potential difference between electrodes).

The process involving transformation of neutral atoms and molecules into positive and negative ions is termed ionization. Ionization, arising in a certain volume of the atmosphere, is volume ionization. Volume ionization, resulting from the high-temperature heating of gas, is termed thermal ionization.

At high temperatures energy of the considerable part of neutral gas molecules is sufficient for their splitting into ions as they collide with each other, furthermore, the temperature growth results in the increase of the total number of collisions between gas molecules. At ultra-high temperatures irradiation of gas and incandescence electrons influence on the process of ionization. Ionization is possible at conventional temperatures too, provided that high speeds are imparted by electric field to electrons and ions of the gas. Having a high energy, these particles can break neutral atoms and molecules into ions. Moreover, light or ultraviolet beams, X-rays or emission of radioactive substances can lead to ionization.

Air like all gases has quite a weak electroconductivity in normal conditions due to low concentration of free electrons and ions. That is why, air gap (or other gaseous medium) between electrodes is to be ionized to generate a high electric current, i.e. an electric arc. Ionization can result from applying a rather high voltage to electrodes; electric field accelerates a few free electrons or ions of the gas; as the result of acquiring a high energy they can break neutral atoms or molecules into ions.

High voltages are not allowed by safety engineering regulations of welding. Therefore, thermal electron and field electron emissions are preferred to carry out research into this process. A lot of free electrons, occurring in metal and having a high kinetic energy, pass to the gaseous medium of the interelectrode space, causing its ionization.

Thermal electron emission involves "vaporization" of free electrons from the surface of metal due to high temperatures. The number of free electrons, acquiring energy sufficient for passing through the energy barrier in the surface layer and leaving the metal is dependent directly on the temperature. The point of field electron (cold) emission is that an outer electric field is developed, which transforms the energy barrier near the surface of metal and supports liberation of electrons with energy sufficient for passing through this barrier.

Gaseous medium ionization is characterized by the degree of ionization, i.e. relation of charged particles in the certain volume to the primary number of particles (before ionization) [3]. Welding is more stable and easier if the ionization potential is low.

Mechanical properties of a weld metal can be improved in a variety of ways. Enhancing strength and operational characteristics of a weld metal is possible via adding a nano-material to it. We consider adding metal nanopowders to liquid glass via ultrasonically induced cavitation by machine UIP 1000hd when manufacturing electrodes for MMA welding. Ultrasonic processor UIP1000hd is widely used in biology, health care, chemistry, and various fields to carry out the following operations: dispersion, homogenization, de-agglomeration, grinding, acoustochemistry, emulsification, bacteria splitting, ultrasonic treatment of liquids in running or periodic mode, constant mixing of various mediums, degassing of liquids, and research into acoustic characteristics of materials [4, 5].

There is not much information on application of nano-materials in welding production available in literature. However, more studies focused on this issue are being carried out these days [2, 6, 7, 8].

Operational characteristics, as well as physical and mechanical properties of metal structures depend both on chemical composition of alloys, they are produced, and on the graininess of their structural elements. The finer the structure is, the better mechanical characteristics of metal structures are. Modification performed at the same time as crystallization is the most typical procedure of grinding structural elements. The efficient method of grinding the structure and enhancing metal characteristics is nanopowder modification of heat-resistant chemical compounds (nitrides, carbides, borides, oxides etc.). However, these powders influence on physical and chemical characteristics of welding alongside with modification.

This paper is aimed at selecting nanostructure elements, which can stabilize the process of welding and regulate crystallization of the weld metal (activator-modifier).

### Main part

Various methods of adding nanopowder to the weldpool are available (through welding flux, via spraying in the shielding gas, submerging the electrode into a mixture of nano-materials, welding over the thin layer of nanopowder scattered on metal), but we suppose it is efficient to add a nanopowder to liquid glass when manufacturing electrodes, since losses of a nanopowder are minimal (a nanopowder doesn't get into the weldpool because of splattering, which is not high when MMA welding); this method of adding nano-modifiers is harmless for human health (nanopowder particles can't be breathed into respiratory organs and do not store in lungs); nanopowder is spread smoothly over the weld joint; the process of electrode manufacturing does not get complicated via adding many processing steps.

Substances used for manufacturing electrode coating are very important for welding [9].

Moreover, nanopowders are distinguished by the following characteristics: low liquid metal wettability, it is extraordinary important for performing crystallization centers; high chemical activity; oxidation starts at relatively low temperatures, so nano-dispersed particles can get deactivated in high temperature zone of a weld pool [10].

Nanopowders are powders with specific nano-dimensions. They differ from compact specimens in minute elements of the structure. Nano-materials can be singled out in a certain class of materials due to their dimensions. The diameter of a nano-particle can not exceed 100 nm according to the definition. The diameter of quite a half of available nanopowders is less 30 nm. The diameter of 9% powders in the nano-group is more 100 nm. Nanopowders of the most of producers have particles with diameter 5 to 100 nm. Prices are fixed according to the size of particles, purity and homogeneity of a powder. Activation energy of numerous processes, which nano-particles take part in, is affected by deformed crystal lattice of nano-particles; consequently, their conventional flow and sequence are changed. The system has an important specific feature: potential response speed of objects is increased, i.e. the smaller the object size is, the faster the process is which this object takes part in.

Almost 80% industrially produced nanopowders consist of metal oxides. Nanopowders of fine metals have a considerable and constantly increasing share of the output. Nearly all hard metal elements are produced as nanopowders of fine metals [11].

Modification based on adding refractory particles and aimed at improving mechanical and operational characteristics of the overlay is used more frequently when welding. Grains in the alloy structure can get smaller due to making use of modifiers with 60-100 nm particles; it is possible because the initial radius of crystallization center is minimal and modifier particles distribute evenly in the molten layer, whereas their mass concentration is low.

This paper presents theoretical research into the effect, which complex (Ti, Zr, Cs) nanopowder has on the efficient ionization potential ( $U_{\text{eff}}$ ) of welding arc discharge.

The energy of atom ionization characterizes the particle and it is independent on the method of ionization, whereas ionization potential characterizes the first historical method of ionization.

The energy of atom ionization, measured in eV (electron-volts) is similar numerically to atom ionization potential, measured in V (volts).

The energy of ionization is an important atom characteristic and influences on the nature and bound strength of chemical compounds made by the atom. The energy of atom ionization has a strong effect on deoxidizing properties of the corresponding elementary substance.

Ionization potential is a relation of electron work function of the substance atom to the electron charge:

$$U = \frac{W}{e}, \quad (1)$$

where  $U$  — ionization potential, V;  $W$  — electron work function, J;  $e$  — electron charge, C.

Complex atoms, consisting of a lot of electrons, have several ionization potentials. The first ionization potential meets electron removal from the shell of the atom, having the weakest bonds with it. The removal of other electrons, which are closer to the atomic nucleus and have stronger bonds, requires more work. Therefore, the second and further ionization potentials, corresponding to removal of the second and further electrons are higher [3].

**Table.** First ionization potentials (U) of elements

Elements	Cs	K	Na	Ca	Zr	Ti	Mg	C	H	O
<i>U</i>	3.88	4.30	5.11	6.11	6.63	6.8	7.64	11.22	13.53	13.56

It is seen from the Table above that cesium, potassium, sodium, calcium, zirconium, titanium etc. have the lowest ionization potentials. Therefore, these substances are added to electrode coatings or fluxes to support stability of welding arc burning.

We should know how elements affect the weldability of a product to avoid difficulties and eliminate problems when welding.

Titanium is used due to its high corrosion resistance. It increases strength, impact strength of steel, improves its weldability, supports grain refinement in conditions of metal crystallization. It combines with carbon when welding, preventing from synthesis of chromium carbides on grain boundaries and intercrystalline corrosion of chromium-bearing steels of a weld joint.

Zirconium additives improve the ultimate strength, increase compression strength, impact strength and plasticity of steels for general engineering purposes [12]. Weldability of an alloy and weld plasticity get better due to structure refinement [13].

Cesium additive enhances enormously heat resistance of magnesium and aluminum, e.g. 0.3 – 0.4 % cesium additive increases impact strength of magnesium three times and its corrosion resistance is improved considerably. In recent years metal cesium has been widely used in industry as an additive to tungsten when manufacturing electrodes of high-capacity arc-discharge lamps and electrodes for argon, helium and hydrogen welding of aluminum, magnesium, titanium, cerium, stainless steel and other active alloys. This additive makes easier arc initiation and burning at low voltages.

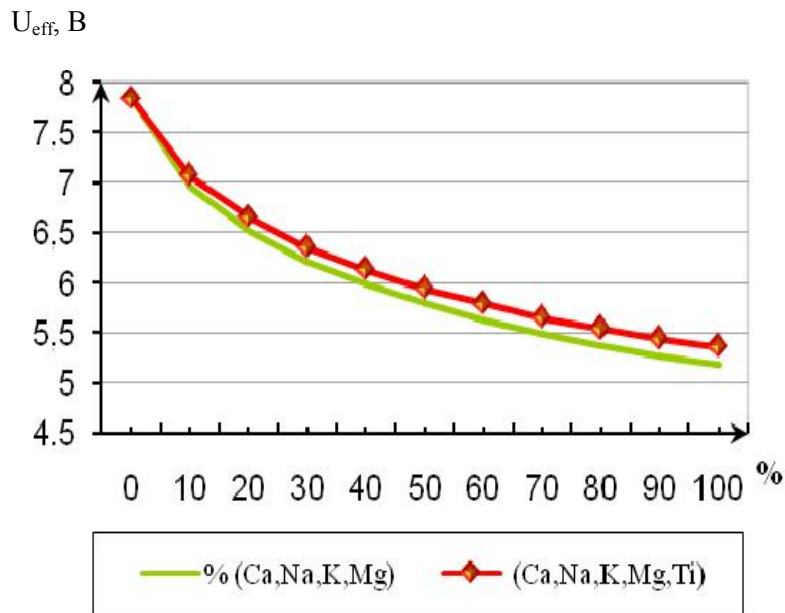
The efficient potential of ionization is potential of a homogeneous gas, producing the same number of charged particles as in the mixture.

As there are several elements in the arc atmosphere formula [6] of  $U_{eff}$  is used:

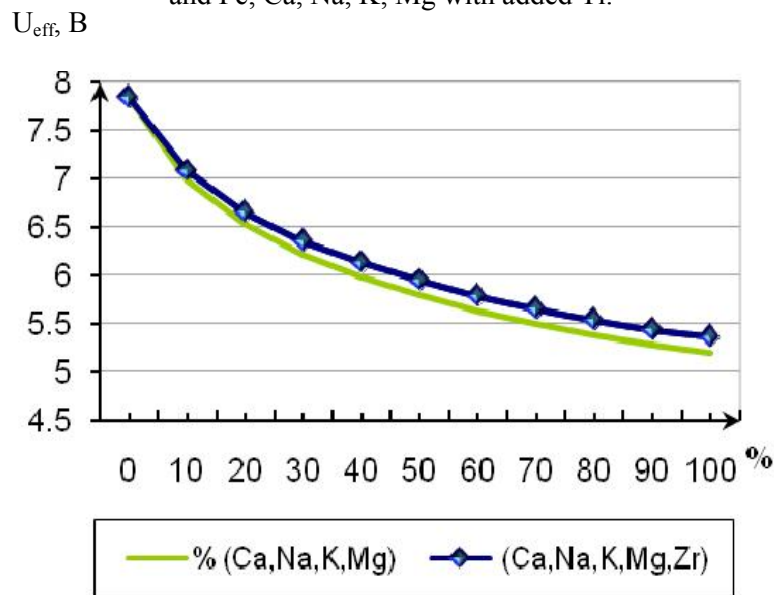
$$U_{eff} = -\frac{T}{5800} \ln \sum_{i=1}^{i=k} \left( C_i^{1/2} \exp \left\{ -\frac{5800}{T} U_i \right\} \right) \quad (2)$$

where  $C_i$  – gas concentration of gas  $i$ ;  $U_i$  – ionization potential of each gas.

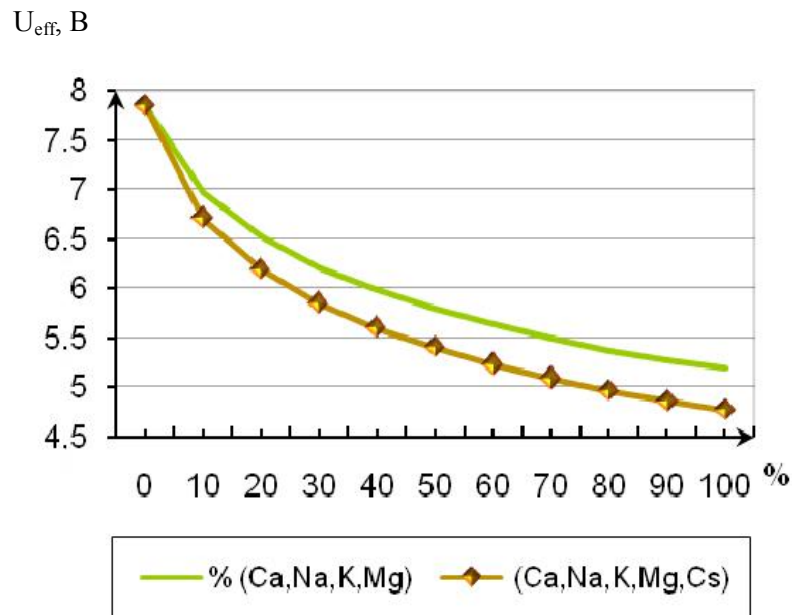
Calculating the efficient ionization potential of vapors of ferrum (Fe), calcium (Ca), sodium (Na), potassium (K), magnesium (Mg) with Ti (Figure 1), zirconium Zr (Figure 2), cesium Cs (Figure 3), we have drawn the diagrams.



**Figure 1** - Change in the efficient potential of ionization for mixed vapors Fe, Ca, Na, K, Mg and Fe, Ca, Na, K, Mg with added Ti.



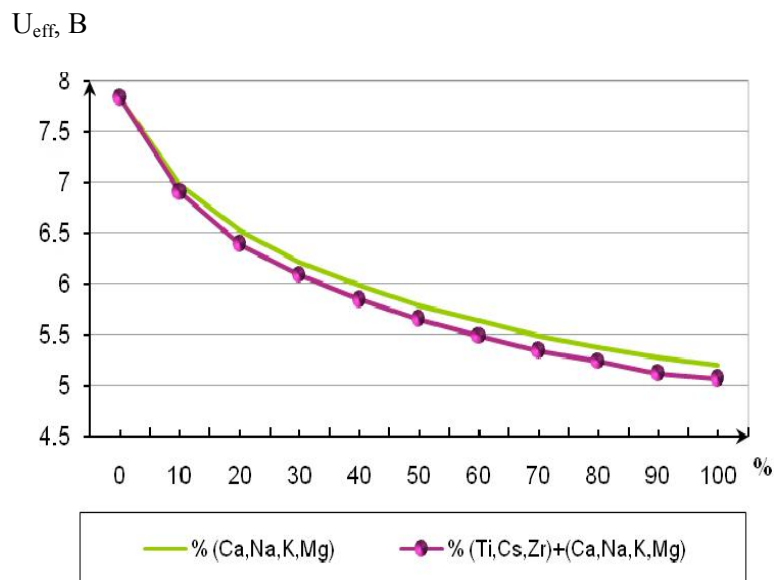
**Figure 2** - Change in the efficient potential of ionization for mixed vapors Fe, Ca, Na, K, Mg and Fe, Ca, Na, K, Mg with added Zr.



**Figure 3** - Change in the efficient potential of ionization for mixed vapors Fe, Ca, Na, K, Mg and Fe, Ca, Na, K, Mg with added Cs.

As one can see from the diagrams, the effective ionization potential is hardly affected via adding Ti, Zr, and it is decreased 6.52 to 6.18 eV provided that mixture containing 20% Cs (mass share) is added.

Having added nanopowder (Ti, Zr, Cs) in equal shares we obtained dependences, depicted in Figure 4.



**Figure 4** - Change in the efficient potential of ionization for mixed vapors Fe, Ca, Na, K, Mg and Fe, Ca, Na, K, Mg with added Ti, Zr, Cs.

The efficient potential of ionization gets decreased via adding the mixture on the whole. It is necessary to add a little component with a low ionization potential to reduce the ionization potential of

the mixture and support burning of the arc. The authors of papers [6, 7] detected a positive effect of a complex nanopowder, containing Ti, Cs, Zr on operational characteristics of the weld joints.

### Conclusion

Nowadays nanopowders are used in various fields, e.g. information technologies, chemical industry, medicine and pharmacology, material science, electronics and welding production. However, it is worth emphasizing, the information on using these powders in welding production is not sufficient.

The theoretical study revealed reducing of the general efficient potential of ionization via adding complex nanopowder, containing Ti, Cs, Zr. Therefore, the process of welding gets more stable.

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