# Hardening (WC-Co) alloys by Nitrogen ions with different energies

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**Abstract:**

In this study, the calculation of Frenkel pairs generated as a result of irradiation of (Tungsten Carbide – Cobalt) alloys with nitrogen ions to different ratios of cobalt concentration, The value of radiation doses were $(3.7\,X10^{19} - 1.5X10^{21}N/cm^2)$.

The hypothetical irradiation was made using nitrogen ions with different energies between (120-180 keV) and a special program was written in "fortran power station 90" to obtain the theoretical results.

According to this study,it was found that increasing in nitrogen ions energy causes increase of $T_{(Max)}$ and decreasing in Frenkel pairs generated by nitrogen ions from the range (120-180)keV, and the best increase was at energy (120keV)in tungsten and limited increase in other two types of atoms ( carbon and cobalt) ,because it's affected by another factors such as changing in temperatures and the ratios of cobalt concentration . These Frenkel pairs are generating dislocations and deformations in crystal lattice which in turn lead to an increase the hardness of these alloys.

**Keywords:** Hardness , Nitrogen ions , Frenkel pair.

# تصليد سبائك (كاربيد التنكستن- كوبلت) بأيونات النتروجين بطاقات مختلفة

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**الخلاصة:**

تم في هذة الدراسة حساب أزواج فرنكل المتولدة نتيجة تشعيع سبائك ( كاربيد التنكستن – كوبلت ) بأيونات النتروجين ولنسب مختلفة من الكوبلت، أذ كان مقدار الجرعات الاشعاعية المستخدمة $(3.7\,X10^{19} - 1.5X10^{21}N/cm^2)$. جرى التشعيع الافتراضي بأيونات النتروجين بمديات طاقية تراوحت بين (120-180 KeV) استحصلت جميع النتائج النظرية من بناء برنامج حسابي "fortran power station 90" خاص بذلك.

بموجب هذه الدراسة، وجد إن زيادة طاقة أيونات النتروجين يؤدي الى زيادة في قيمة الطاقة الحركية $T_{(Max)}$وكذلك يؤدي إلى نقصان في عدد أزواج فرنكل المتولدة نتيجة التشعيع بهذه الجسيمات ولمدى طاقي (120-180)KeV، وافضل زيادة كانت عند قيمة (120keV)في التنكستن بينما هناك زيادة طفيفة في النوعين الاخرين من الذرات (الكاربون والكوبلت) ،نتيجة تاثرها بعوامل اخرى مثل التغير في درجات الحرارة ونسب تراكيز الكوبلت وهذه الزيادة في أزواج فرنكل تولد انخلاعات وتشوهات في الشبيكة البلورية تؤدي بالنتيجة إلى زيادة الصلادة لهذه السبائك.

**الكلمات المفتاحية:** الصلادة ، ايونات النتروجين ، ازواج فرنكل.

## 1. Introduction

The advent of Tungsten Carbide or hard metals began with the idea of replacing costly diamond wire drawing dies for Tungsten filaments.This group of sintered materials (WC-Co) had a high level of hardness and wire resistance.The history of cemented carbide began in Germany during the first world war when K.Schroter of Osram studiengesellschaft succeeded in producing the alloy [1].

Hardening (which means the resistance to surface indentation, i.e. the resistance that the body shows when penetrating another body harder than it and could not make permanent distortions), is the most important mechanical property which could not be explained by a simple concept. For getting a good result one most select the propose load and indenter tool which has an appropriate form according to the type of tested sample and the hardness degree[2].

Hardening metals by Irradiation is a recent technique in the field of hard metals. Which could be done when projected metal with one of nuclear particles that have high energy such as neutrons, electrons, alpha particles or protons.

One example of metal that could be Hardened with irradiation is WC-Co Alloys, Due to the importance of these alloys in different industrial uses. It could be pointed to some of previous studies that include Hardening of different alloys with irradiation theoretically and practically are:

First who produced this idea dr. N. A. Askouri (1974-1975) by introducing a practical researches include increasing in the hardness of WC-Co Alloys with different ratios of cobalt by using increasing doses of heavy charged particles(protons with 10 MeV, helium ions, 30 MeV) from Nuffield cyclotron where the increasing of hardness is to about 30%[3,4,5].

In 2000 K.Farrell and et.al. studying tension stress by Irradiation of pure (Fe) commercial sample and (Cu-Fe) alloys and two samples of Fe-steel by electrons with energy (2.5 K eV) with doses $(2.82\,X10^{23} - 9.35\,X10^{23}\ \frac{electron}{m^2})$ [6].

In 2002 I.wase and his group propelling a study include Irradiation of two samples of ( Fe-0.6wt% Cu ) and ( Fe -1.2wt % Cu ) with heavy ions[7].

In 2004 T.Kitao and his group propelling a study include Irradiation hardness and enveloping the microscopic structure as a resulting of Irradiation with neutrons and electrons for( Fe) pure and for typical (Fe –Cu) alloys [8].

## 2. Theory

The most important thing to know is the relation between W–C, Co–C, and Co–W. Phase equilibria in ternary systems of transition metals and carbon are determined by the crystalline structure and thermodynamic properties of the carbides formed in the binary Me–C systems, as well as the interaction of the transition metals with each other. The size factors of the two components are of decisive significance in the formation of simple binary solid solutions.

The basic factors determining the conditions for the formation of continuous solid solutions include: (1) identical crystalline structure with similar values of lattice periods, (2) identical types of chemical bond, (3) presence in the compositions of elements with small difference in atomic radii, and (4) identical stoichiometric composition [9].

(WC) grains are approximately hard and brittle, and the Grain of connected phase are soft and ductile. Each grain of (WC) grains and (Co) contain a whopper number of unit cells, and this number differs with the difference of grain size [10].

WC-Co alloys has many industrial uses: cutting tools, wear drawing dies,rocks drills(used in looking for petrol), in some parts as a resistance to chemical erosion and wear and also in some refractory resistance parts[11].

If a beam of particles having a radiation flux$\varphi$ (particles / $cm^2$ sec)with high energy incident on a specific target which has atoms density $N_\circ$(atom/$cm^3$) , the number of atoms displaced about its positions for the primary knock on atoms caused by the colliding with the ejected particles $n_p$ (atom / $cm^3$) So, the relation mathematically is [11,12,13]:

$$n_p = \varphi\, t\, N_0\, \sigma_d \quad \text{…………(1)}$$

Where:

t : Time of exposed irradiation (sec).

$\sigma_d$ : The displacement cross section, which represent the probability of atomic displacement for a specific type of lattice atoms ,the unit is ( $cm^2$)or other unit (barn ).

If supposing that the primary knock –on atoms (PKAs) will recoil and making a series of secondaries and tertiaries displacements and so on… until it loses all of their energies and being in rest. So, the number of atoms displaced for this series resulting form the (PKAs) which represent the number of Frenkel pairs generated (F p/ $cm^3$) shown below[3,10,14] :

$$n_d = n_p\, \tilde{\vartheta} = \varphi\, t.\, N_0\, \sigma_d \tilde{\vartheta} \quad \text{…....(2)}$$

Where :

$n_d$ : Represents number of Frenkel pairs generated (Fp / $cm^3$) from the

$\tilde{\vartheta}$ : Average number of Displacement atoms by one (PKA) atom resulting from a series of displacements which happened later and it could be found from the relation below[14,16]:

$$\left[ \bar{\nu} = \frac{1}{2}\left[\frac{T_{max}}{T_{max} - E_d}\right]\left[1 + Ln\left[\frac{T_{max}}{2E_d}\right]\right] \text{..................(3)} \right]$$

$T_{(max)}$: Represents the maximum transferred energy for the lattice atom result from the head-on elastic collision .

$E_d$ : Threshold energy required to displace the atom about its lattice position, it has a constant value about 25 eV.

$\tilde{\vartheta}$ depends on average transferred energy to the multiplied atom $E_{p(ave)}$.

So we can calculate maximum energy transferred $T_{(max)}$ from the ejected particle to the rest atoms lattice (supposing that the type of collision is Head –On Elastic Collision) between the two colliding particles [14], the amount of energy lost by the neutron in each collision alone could be calculated from the solution of conserving energy and conserving linear momentum equations, the final equation will be in the form [15]:

$$T_{max} = \frac{4\, M_1 M_2}{(M_1 + M_2)^2}\, E \quad \text{……(4)}$$

$\overline{E_p}$ which represent the average transferred energy for the primary atom (PKA) could be calculated as a result of colliding with the incident charged particle from the equation below[11,15] :

$$\overline{E_p} = \left[\frac{E_d\, T_{(max)}}{T_{(max)} - E_d}\right] \ln\left[\frac{T_{(max)}}{E_d}\right] \text{…..(5)}$$

Where :

When ( $T_{(max)} \gg E_d$ ) equation (5) become in the form :

$$\overline{E_p} = E_d \ \ln\left[\frac{T_{(max)}}{E_d}\right] \qquad \ldots\ldots..(6)$$

## 3. Calculations:

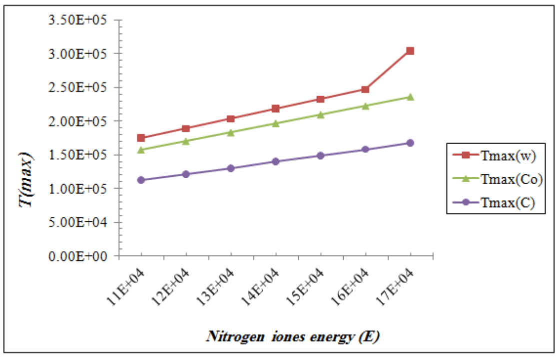
The most important work in this study was to find a relation between the number of frenkel pairs with a specific range of nitrogen ions energies.

The value of radiation dose was ranging between $(3.7\,X10^{19} - 1.5X10^{21}N/cm^2)$ with range of energies between ( 120 -180 KeV) and to different ratios of cobalt concentration , a special program was written called " Fortran Power Station 90 "and this program basically depends on the equations and mathematical relations.

## 4. Results and Discussion

Figure (1) shows the relation between the maximum transferring energy to the collided atom $T_{max}$ (KeV) and the energy of the incident particle E (KeV).$T_{max}$ calculated from the relation (4) for the three internal atoms which are carbon, cobalt and tungsten atoms.

From figure (1) it could be noticed that $T_{max}$ increases linearly with the increasing of incident particles energy.




**Figure(1)Relation between nitrogen ions energy and T(max) for target atoms**

Figure (2) shows the relation between the average transferred energy to the primary knock-on atoms $\overline{E_p}$ (KeV) and the energy of the incident particle E (KeV).$\overline{E_p}$calculated from the relation (7) for the same three atoms and same incident particles.

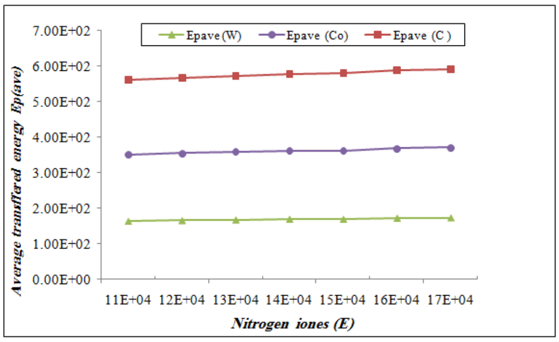



**Figure (2)Relation between nitrogen ions energy and Ep(ave) for target atoms**

From figure(2), it could be noticed that $\overline{E_p}$ (KeV) is limitedincreased in linearly form with the increasing of incident particles energy( E) and for the same type of atoms.

Figure (3) shows the relation between nitrogen ions energy and frenkel pairs with cobalt concentrations (6%) for total alloy.

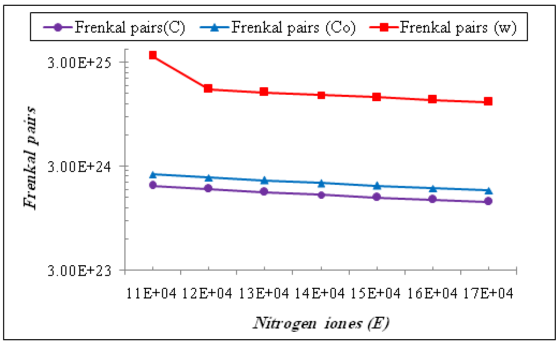
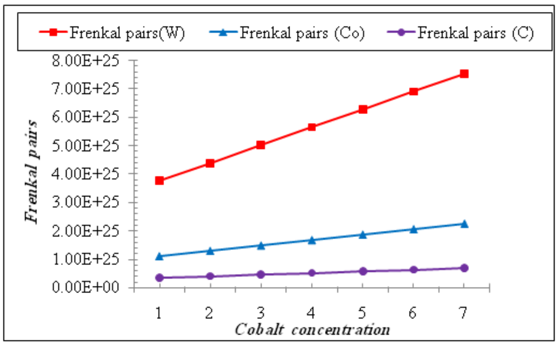



**Figure (3)Relation between nitrogen ions energy and frenkal pairs(FP/ cm$^3$) with cobalt concentration( 6% ) for total alloy**

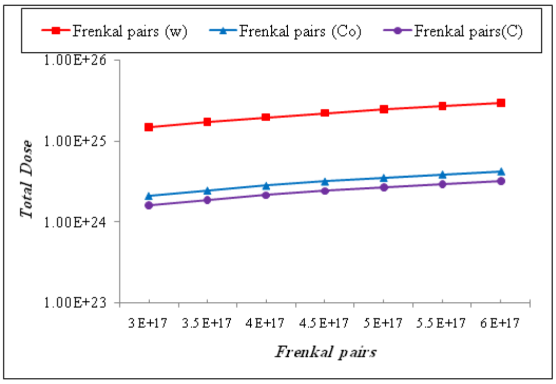
From figure(3), it could be noticed that frenkel pairs ($n_d$) increased at energy 120 keV for tungsten atoms and decreased with the increase of incident particles energy (E) and for the same atoms.

Figure(4) shows the relation between Cobalt concentration(6%) and Frenkal pairs with energy 150 keV.




**Figure(4) Relation between Cobalt concentration and Frenkal pairs with energy 150KeV**

From figure (4), it could be noticed that ($n_d$) increased linearly with the increase of cobalt concentration for total aolly.




**Figure(5) shows the relation between radiation dose and Frenkal pairs with energy 150KeV.**

From figure (5), it could be noticed that ($n_d$) increased logarithmically with the increase of radiation dose for total alloy with energy 150KeV.

The increase in hardness could be explained to less dislocations movement, (Pratt) explain irradiation hardening result from climb the edge dislocation outside the plane surface as a result to Frenkel pairs (dislocations – vacancies), But according to (Seitz) the climb of edge dislocation decrease the vibrating this lead to less movement[11].

So, the increase in hardness after irradiation result from the atomic displacements which happen between atoms inside the crystalline lattice and this lead to distort atoms that rest in it's position, So this will distort the crystalline surfaces on each other[4].

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## 5. Conclusion

1. Frenkel pairs decreased with the increasing energy of incident particles (nitrogen ions) because it's affected by other factors such as changing in temperatures and the ratios of cobalt concentration in the alloy.
2. When using hypothetical irradiation best increase was at energy (120keV) in tungsten atoms and limited increase in other two types of atoms ( carbon and cobalt) as compared with practical value (150keV).
3. The increase of incident particles (nitrogen ions) will increase the energy of colliding atoms ($T_{Max}$).
4. Frenkel pairs increase with the increase of radiation dose.
5. Hardness increase with increase of frenkel pairs.

## 6. References

**[1]** kolaska, H., powder met. Int, Vol.25, P.311(1992).

**[2]** ف. بيلي، ترجمة د. حسين باقر،"مبادئ هندسة المعادن والمواد"، الجامعة التكنلوجية العراق (١٩٨٥)

**[3]** N.A.Askouri , International Journal Applied Radiation Isotopes , Vol. 26, P.61,(1975).

**[4]** N.A.Askouri, ph, D., thesis, univ. of Birmingham, U.K,(1974).

**[5]** J.H.Fremlin and N.A.Askouri , Nature journal , Vol.249 , No.5453 , P.137,(1974).

**[6]** K.Farrell,R.E.Stoller , P.Jung ,” Journal of Nucl.Materials” , Vol.179, P. 77, (2000).

**[7]** A.Iwase, T.Hasegawa , Y.Chimi , “Nucl.instr.and methods in phy.research section B”, Vol.195, P.309, (2002).

**[8]** T.Kitao, R.Kasada , A.Kimura .”Digital Library “stp1447-eb/stp11240s , p.11 , (2004) .

**[9]** Gopal S. Upadhyaya , Cemented Tungsten Carbides Production Properties and Testing, Elsevier Science,1998.

**[10]** L.F. Mattheise and D.R.Haman , “Bulk and surface electronic structure of hexagonal WC” , phy.Rev.B,30(1984)1731.

**[11]** L.T.Chadderton, "Radiation damage in crystals" , new yourk , and sons INC, 1 th ed. ,(1965).

**[12]** G. J. Dienes and G. H. Vineyard, "Radiation effects in solids" , Inter science publisher , INC,(1957).

**[13]** J.N.Anuo, " Radiation effects on materials" , Hemisphere pub. Corp, USA,(1984).

**[14]** تغريد مسلم، "تصليد سبائك كاربيد التنكستن – كوبلت بالتشعيع بجسيمات مشحونة ثقيلة"،رسالةماجستير، كلية التربية\ ابن الهيثم، جامعة بغداد، ١٩٩٧

**[15]** د. منيب عادل خليل،"الفيزياء النووية" ، 1994 , جامعة الموصل

**[16]** J.N. Anno , “ Notes On Radiation Effects On Materials “Hemisphere Pub. , (1984).