# Superconducting State Parameters of Ternary Amorphous Superconductors

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The theoretical investigation of superconducting state parameters (SSP) such as electron-phonon coupling strength $\lambda$, Coulomb pseudo-potential $\mu^*$, transition temperature $T_C$, isotope effect exponent $\alpha$, and the effective interaction strength $N_O V$ of $(Ni_{33}Zr_{67})_{1-x}M_x$ ($x =$ 0, 0.05, 0.1, 0.15, $M = V$) for ternary amorphous superconductors has been reported using Ashcroft's empty core model potential. Five local field correction functions proposed by Hartree, Taylor, Ichimaru-Utsumi, Farid et al., and Sarkar et al. are used in the present investigation to study the screening influence on the aforesaid properties. The $T_C$ obtained from Sarkar et al. local field correction function were found to be in an excellent agreement with the available theoretical data. A quadratic $T_C$ equation has been proposed, which provides successfully the $T_C$ values of ternary amorphous alloys under consideration. Also, the present results are found in qualitative agreement with other such earlier reported data thus confirming the superconducting phase in the superconductors.

## 1. Introduction

During the last several years, superconductivity remained a dynamic area of research in condensed matter physics with continual discoveries of novel materials and with an increasing demand for novel sophisticated devices and technological applications. Stable ternary glasses can be formed by adding a third element ($M$) to binary metallic glasses. These are of interest since the third element can modify the physical properties of binary metallic glasses and can also be used as a probe to study the host. The influence of third element on the electronic and electron transport properties of binary metallic glasses have been studied extensively [1-4], but its effect on superconducting properties has been given lesser attention. Only a few researchers have studied the properties of ternary amorphous superconductors using model potential formalism [4-12].

The study of superconducting state parameters (SSP) of the ternary amorphous superconductors may be of great help in deciding their applications. For instance, a study of the dependence of transition temperature $T_C$ on the composition of metallic elements can be helpful in finding new high $T_C$ superconductors. Applying pseudo-potential to ternary amorphous superconductors requires that pseudo-ions with average properties are assumed to replace three types of ions in the ternary systems and a gas of free electrons that is assumed to permeate through them. The interaction between electron and pseudo-ion is accounted by the pseudo-potential and the electron-electron interaction involving a dielectric screening function. For a successful prediction of superconducting properties of the alloying system, a proper selection of the pseudo-potential and screening function is very essential [6-11].

Therefore, we decided to investigate the superconducting behavior of $(Ni_{33}Zr_{67})_{1-x}M_x$ ($x =$ 0, 0.05, 0.1, 0.15, $M = V$) ternary amorphous superconductors. In this paper, we have used the well-known McMillan's theory [13] of superconductivity to predict the superconducting state parameters of ternary amorphous superconductors. We have used Ashcroft's empty core (EMC) model potential [14] for the first time to study electron-phonon coupling strength $\lambda$, Coulomb pseudo-potential $\mu^*$, transition temperature $T_C$, isotope effect exponent $\alpha$, and effective interaction strength $N_O V$. To see the impact of various exchange and correlation functions on the aforesaid properties, we have employed here five different types of local field correction functions proposed by Hartree (H) [15], Taylor (T) [16], Ichimaru-Utsumi (IU) [17], Farid et al. (F) [18] and Sarkar et al. (S) [19]. We have incorporated, for the first time, a more advanced local field correction functions due to IU [17], F [18] and S [19] with EMC model potential in the

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present computation of SSP for ternary amorphous superconductors. Actually, our main aim of the present study is to check the validity of appropriate local field correction functions. Therefore, we have used various types of local field correction functions in the present computation.

In the present work, the pseudo-alloy-atom (PAA) model was used to explain electron-ion interaction for alloying systems [6-10]. It is well known that PAA model is a more meaningful approach to explain such a kind of interactions in alloying systems. In the PAA approach a hypothetical monoatomic crystal is supposed to be composed of pseudo-alloy-atoms occupying the lattice sites and forming a perfect lattice in the same way as pure metals. In this model the hypothetical crystal made up of PAA is supposed to have the same properties as the actual disordered alloy material and the pseudo-potential theory is then applied to study various properties of an alloy and metallic glass. The complete miscibility in the alloy systems is considered as a rare case. Therefore, in such alloying systems the atomic matrix elements in the pure states are affected by the characteristics of alloys such as lattice distortion effects and charging effects. In the PAA model, such effects are involved implicitly. In addition to this, it also takes into account the self-consistent treatment implicitly. Looking at the advantage of the PAA model, we propose for the first time the use of this model to investigate the superconducting state parameters of ternary amorphous alloys.

## 2. Theoretical Methodology

The well known screened Ashcroft's EMC potential [14] used in the present computation of SSP for ternary amorphous alloys is of the form

$$W(X) = \frac{-2\pi Z}{\Omega_O X^2 k_F^2 \varepsilon(X)} \cos(2k_F X r_C) \qquad (1)$$

Where, $r_C$, is the parameter of model potential of ternary alloys. The EMC model potential is a simple one-parameter model potential [15], which has been successfully found for various metallic complexes with various forms of the screening functions [3-12]. We use EMC model potential with more advanced Ichimaru-Utsumi [18], Farid et al. [19] and Sarkar et al. [20] local field correction functions. The model potential parameter $r_C$ may be obtained by fitting either to some experimental data or to realistic form factors, or other data relevant to the properties to be investigated. Here, $r_C$ is fitted with experimental $T_C$ of the ternary amorphous alloys for most of the local field correction functions. Moreover, for $(Ni_{33}Zr_{67})_{1-x}M_x$ ( $x =$ 0, 0.05, 0.1, 0.15, $M = V$ ) ternary amorphous superconductors, the electron-phonon coupling strength $\lambda$ is computed using the relation [3-12]

$$\lambda = \frac{m_b \Omega_0}{4\pi^2 k_F M \langle \omega^2 \rangle} \int_0^{2k_F} q^3 \left| W(q) \right|^2 dq \qquad (2)$$

Here $m_b$ is the band mass, which is taken unity for the sake of simplicity, $M$ is the ionic mass, $\Omega_O$ is the atomic volume, $k_F$ is the Fermi wave vector, $W(q)$ the screened pseudo-potential, and $\langle \omega^2 \rangle$ is the phonon frequency of the ternary amorphous alloys, which is calculated using the relation given by Butler [20], $\langle \omega^2 \rangle^{1/2} = 0.69\,\theta_D$, where $\theta_D$ is the Debye temperature of the ternary amorphous alloys.

Using $X = q/2k_F$ and $\Omega_O = 3\pi^2 Z/(k_F)^3$, we obtain equation (2) as

$$\lambda = \frac{12 m_b Z}{M \langle \omega^2 \rangle} \int_0^1 X^3 \left| W(X) \right|^2 dX \qquad (3)$$

Where, $Z$ and $W(X)$ are the valence and the screened EMC pseudopotential [14] of the ternary amorphous alloys, respectively.

The BCS theory gives a relation $T_C \approx \theta_D \exp(-1/N(0)V)$ for superconducting transition temperature $T_C$ in terms of Debye temperature $\theta_D$. The electron-electron interaction $V$ consists of the attractive electron-phonon-induced interaction minus the repulsive Coulomb interaction. The notation used is: $\lambda = N(0)V_{e-ph}$. The Coulomb repulsion, $N(0)V_C$, is called $\mu$ so that $N(0)V = \lambda - \mu^*$, where $\mu^*$ is a "renormalized" Coulomb repulsion, reduced in value from $\mu$ to $\mu/[1+\mu \ln(\omega_P/\omega_D)]$. This suppression of the Coulomb repulsion is a result of the fact that the electron-phonon attraction is retarded in time by an amount $\Delta t \approx 1/\omega_D$, whereas the repulsive screened Coulomb interaction is retarded by a much smaller time, $\Delta t \approx 1/\omega_P$ where $\omega_P$ is the electronic plasma frequency. Therefore, $\mu^*$ is bounded above by $1/\ln(\omega_P/\omega_D)$, which for

conventional metals should be ≤ 0.2. Values of $\lambda$ are known to range from ≤ 0.10 to ≥ 2.0. Also, the parameter $\mu^*$ is assigned a value in the range 0.10-0.15 that is consistent with tunneling and with theoretical guesses. Calculations of $\mu$ or $\mu^*$ are computationally demanding and are not yet under theoretical control. Calculations of $\lambda$ are slightly less demanding and under somewhat better theoretical control, and have been attempted for many years. Prior to 1990, calculations of $\lambda$ generally required knowing the phonon frequencies and eigenvectors as input information, and approximating the form of the electron-ion potential. McMillan [13] and Hopfield [21] pointed out that one could define a simpler quantity, $\eta = N(0)\langle I^2\rangle$ with $\langle\omega^2\rangle = \frac{2}{\lambda}\int_0^\infty d\Omega\Omega\alpha^2 F(\Omega)$. The advantage of this is that $\eta$ and $\langle I^2\rangle$ are purely "electronic" quantities, requiring no input information about phonon frequencies or eigenvectors. Later, Gaspari and Gyorffy [22] invented a simplified algorithm to calculate $\eta$ which was used by many other authors. These calculations generally require a "rigid ion approximation" or some similar guess for the perturbing potential felt by electrons when an atom has moved. Given $\eta$, one can guess a value for $\langle\omega^2\rangle$ (for example, from $\theta_D$). In the weak coupling limit of the electron-phonon interaction, the fundamental equations of the BCS theory can be derived from the Eliashberg equations. This conversion is possible upon some approximation of the phonon frequency $|\omega| \geq \omega_D$ with $\omega_D$ denote the Debye frequency [23]. Morel and Anderson [24] have given the relation for transition temperature as $\lambda - \mu^* = \lambda - \mu/[1+\mu\ln(E_F/\omega_l)]$, which is nearly equal to the factor 6 for monovalent, bivalent and tetravalent metals. Where $E_F = k_F^2$ is the Fermi energy and $\omega$ the phonon frequency of the metallic substances. The effect of phonon frequency is very small in comparison to the Fermi energy. Hence, the overall effect of the Coulomb pseudo-potential is reduced by the large logarithmic term. Therefore, Rajput and Gupta [25] have introduced the new term $20\,\theta_D$ in place of the phonon frequency $\omega_l$ from the Butler's [20] relation for the sake of simplicity and ignoring the lattice vibrational effect, which generated consistent results for Coulomb pseudo-potential. The parameter $\mu^*$ represents the effective inter-electronic Coulomb repulsion at the Fermi surface [23]. Hence, in the present case, we have adopted the Coulomb pseudo-potential relation given by Rajput and Gupta [25]. Therefore, the Coulomb pseudo-potential $\mu^*$ is given by [6-11, 25]

$$\mu^* = \frac{\frac{m_b}{\pi k_F}\int_0^1 \frac{dX}{\varepsilon(X)}}{1+\frac{m_b}{\pi k_F}\ln\left(\frac{E_F}{20\,\theta_D}\right)\int_0^1 \frac{dX}{\varepsilon(X)}} \qquad (4)$$

As it is evident from Eqn. 4 (originally derived by Bogoliubov et al. [23]) that the Coulomb repulsion parameter, $\mu^*$, is essentially weakened owing to a large logarithmic term in the denominator. Here, $\varepsilon(X)$ the modified Hartree dielectric function, which is written as [15]

$$\varepsilon(X) = 1+(\varepsilon_H(X)-1)(1-f(X)) \qquad (5)$$

$\varepsilon_H(X)$ is the static Hartree dielectric function [15] and $f(X)$ is the local field correction function. In the present investigation, the local field correction functions due to [15], [16], [17], [18] and [19] are incorporated to see the impact of exchange and correlation effects.

The Hartree screening function [15] is purely static and does not include the exchange and correlation effects. It can be expressed as:

$$f(q) = 0 \qquad (6)$$

Taylor [16] has introduced an analytical expression for the local field correction function, which satisfies the compressibility sum rule exactly. This is the most commonly used local field correction function and covers the overall features of various local field correction functions proposed before 1972. According to Taylor [16], it is expressed as:

$$f(q) = \frac{q^2}{4k_F^2}\left[1+\frac{0.1534}{\pi k_F^2}\right] \qquad (7)$$

The Ichimaru-Utsumi local field correction function [17] is a fitting formula for the dielectric screening function of degenerate electron liquids at metallic and lower densities. It accurately reproduces the Monte-Carlo results and also satisfies the self consistency condition in the compressibility sum rule and short range correlations. The fitting formula is

$$f(q) = A_{IU}Q^4 + B_{IU}Q^2 + C_{IU} + \left[A_{IU}Q^4 + \left(B_{IU} + \frac{8A_{IU}}{3}\right)Q^2 - C_{IU}\right]\left\{\frac{4-Q^2}{4Q}\ln\left|\frac{2+Q}{2-Q}\right|\right\} \quad (8)$$

On the basis of Ichimaru-Utsumi local field correction function [17], Farid et al. [18] have given a local field correction function of the form

$$f(q) = A_F Q^4 + B_F Q^2 + C_F + \left[A_F Q^4 + D_F Q^2 - C_F\right]\left\{\frac{4-Q^2}{4Q}\ln\left|\frac{2+Q}{2-Q}\right|\right\} \quad (9)$$

Based on Eqns. 8-9, Sarkar et al. (S) [19] have proposed a simple form of local field correction function given as

$$f(q) = A_S\left\{1 - \left(1 + B_S Q^4\right)\exp\left(-C_S Q^2\right)\right\} \quad (10)$$

Where, $Q = q/k_F$ and parameters $A_{IU}$, $B_{IU}$, $C_{IU}$, $A_F$, $B_F$, $C_F$, $D_F$, $A_S$, $B_S$ and $C_S$ are the atomic volume dependent parameters of IU, F and S-local field correction functions. The mathematical expressions of these parameters are given in papers on the local field correction functions [17-19].

After evaluating $\lambda$ and $\mu^*$, the transition temperature $T_C$ and isotope effect exponent $\alpha$ are investigated using the McMillan's formula [6-13]

$$T_C = \frac{\theta_D}{1.45}\exp\left[\frac{-1.04(1+\lambda)}{\lambda - \mu^*(1+0.62\lambda)}\right] \quad (11)$$

$$\alpha = \frac{1}{2}\left[1 - \left(\mu^* \ln\frac{\theta_D}{1.45T_C}\right)^2 \frac{1+0.62\lambda}{1.04(1+\lambda)}\right] \quad (12)$$

The expression for effective interaction strength $N_O V$ is studied using [6-12]

$$N_O V = \frac{\lambda - \mu^*}{1 + \frac{10}{11}\lambda}. \quad (13)$$

### 3. Results and Discussion

The values of input parameters for $(Ni_{33}Zr_{67})_{1-x}M_x$ ($x$= 0, 0.05, 0.1, 0.15, $M = V$) ternary amorphous superconductors under investigation are assembled in Table 1. To determine the input parameters and various constants for PAA model [6-10], the following definitions $A_{1-x}B_x$ are adopted,

Table 1: Input parameters and other constants.

| Superconductors | $Z$ | $r_C$ (au) | $\Omega_O$ (au)$^3$ | $M$ (amu) | $\theta_D$ (K) |
|---|---|---|---|---|---|
| $(Ni_{33}Zr_{67})_1V_0$ | 3.34 | 1.4584 | 129.76 | 80.49 | 343.47 |
| $(Ni_{33}Zr_{67})_{0.95}V_{0.05}$ | 3.42 | 1.3988 | 127.95 | 79.01 | 345.30 |
| $(Ni_{33}Zr_{67})_{0.90}V_{0.10}$ | 3.51 | 1.3457 | 126.14 | 77.54 | 347.12 |
| $(Ni_{33}Zr_{67})_{0.85}V_{0.15}$ | 3.59 | 1.2918 | 124.33 | 76.06 | 348.95 |

$$Z = (1-x)(Z_A) + x(Z_B) \quad (14)$$

$$M = (1-x)(M_A) + x(M_B) \quad (15)$$

$$\Omega_O = (1-x)(\Omega_{OA}) + x(\Omega_{OB}) \quad (16)$$

$$\theta_D = (1-x)(\theta_{DA}) + x(\theta_{DB}) \quad (17)$$

Where, $x$ is the concentration factor of the second metallic component. The input parameters such as $Z$, $\Omega_O$ and $M$ of the pure metallic components are taken from the literature [11]. Our calculated results of SSP are given in Table 2 along with other theoretical [11] and experimental [4] findings. The graphical representation of the model potential parameter $r_C$ with the concentration ($x$) of 'V' are plotted in Fig. 1. Also, the graphical analysis of the superconducting state parameters of $(Ni_{33}Zr_{67})_{1-x}M_x$ ($x$= 0, 0.05, 0.1, 0.15, $M = V$) ternary amorphous superconductors are also plotted in Figs. 2-6.

Table 2: Superconducting state parameters of $(Ni_{33}Zr_{67})_{1-x}V_x$ ternary superconductors.

| Superconductors | SSP | Present results | | | | | Others | Expt. |
|---|---|---|---|---|---|---|---|---|
| | | H | T | IU | F | S | [11] | [4] |
| $(Ni_{33}Zr_{67})_1V_0$ | $\lambda$ | 0.4796 | 0.6909 | 0.7160 | 0.7302 | 0.5671 | 0.553 | - |
| | $\mu^*$ | 0.1443 | 0.1575 | 0.1593 | 0.1597 | 0.1519 | 0.14 | - |
| | $T_C$ (K) | 1.2638 | 5.5337 | 6.1223 | 6.5066 | 2.6805 | 2.6734 | 2.68 |
| | $\alpha$ | 0.2598 | 0.3579 | 0.3628 | 0.3671 | 0.3080 | 0.341 | - |
| | $N_OV$ | 0.2348 | 0.3291 | 0.3387 | 0.3445 | 0.2753 | 0.275 | - |
| $(Ni_{33}Zr_{67})_{0.95}V_{0.05}$ | $\lambda$ | 0.4652 | 0.6622 | 0.6846 | 0.6978 | 0.5471 | 0.545 | - |
| | $\mu^*$ | 0.1433 | 0.1564 | 0.1582 | 0.1585 | 0.1508 | 0.146 | - |
| | $T_C$ (K) | 1.0417 | 4.7526 | 5.2526 | 5.5980 | 2.2523 | 2.2505 | 2.25 |
| | $\alpha$ | 0.2437 | 0.3472 | 0.3521 | 0.3567 | 0.2945 | 0.311 | - |
| | $N_OV$ | 0.2262 | 0.3158 | 0.3245 | 0.3300 | 0.2647 | 0.266 | - |
| $(Ni_{33}Zr_{67})_{0.90}V_{0.10}$ | $\lambda$ | 0.4580 | 0.6439 | 0.6643 | 0.6766 | 0.5358 | 0.538 | - |
| | $\mu^*$ | 0.1424 | 0.1551 | 0.1569 | 0.1572 | 0.1496 | 0.151 | - |
| | $T_C$ (K) | 0.9686 | 4.3611 | 4.8023 | 5.1187 | 2.0804 | 1.9498 | 2.08 |
| | $\alpha$ | 0.2395 | 0.3420 | 0.3466 | 0.3513 | 0.2899 | 0.285 | - |
| | $N_OV$ | 0.2228 | 0.3083 | 0.3164 | 0.3216 | 0.2597 | 0.260 | - |
| $(Ni_{33}Zr_{67})_{0.85}V_{0.15}$ | $\lambda$ | 0.4449 | 0.6172 | 0.6353 | 0.6464 | 0.5185 | 0.534 | - |
| | $\mu^*$ | 0.1415 | 0.1540 | 0.1558 | 0.1561 | 0.1485 | 0.154 | - |
| | $T_C$ (K) | 0.8196 | 3.7519 | 4.1234 | 4.3972 | 1.7911 | 1.7836 | 1.79 |
| | $\alpha$ | 0.2257 | 0.3311 | 0.3356 | 0.3404 | 0.2784 | 0.266 | - |
| | $N_OV$ | 0.2161 | 0.2967 | 0.3040 | 0.3089 | 0.2515 | 0.256 | - |

The calculated values of the electron-phonon coupling strength $\lambda$ for $(Ni_{33}Zr_{67})_{1-x}M_x$ ($x$= 0, 0.05, 0.1, 0.15, $M=V$) for ternary amorphous superconductors (using five different types of the local field correction functions with EMC model potential) are shown in Table 2 along with other theoretical data [11]. The graphical nature of $\lambda$ is also displayed in Fig. 2. One may notice that the percentile influence of the various local field correction functions with respect to the static H-screening function on the electron-phonon coupling strength $\lambda$ is 16.53%-52.25% for $(Ni_{33}Zr_{67})_{1-x}M_x$ ($x$= 0, 0.05, 0.1, 0.15, $M=V$) for ternary amorphous superconductors**,** respectively. It is also observed from Table 2 that, $\lambda$ decreases from the values of 0.7302→0.4459 as the concentration '$x$' of 'V' is increased from 0.0→0.15. The decrease in $\lambda$ with concentration '$x$' of 'V' shows a gradual transition from weak coupling behaviour to intermediate coupling behaviour of electrons and phonons, which may be attributed to an increase of the hybridization of sp-d electrons of 'V' with increasing concentration ($Z$). This may also be attributed to the increasing role of ionic vibrations in the V-rich region. Our computed $\lambda$ from S-local field correction function is found to have an excellent agreement with available theoretical data [11].

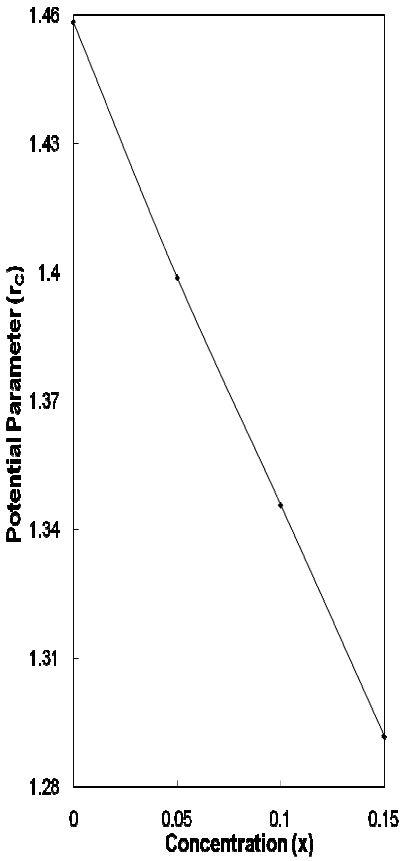


Fig.1: Variation of the model potential parameter $r_C$ with V-concentration $x$ (at %).

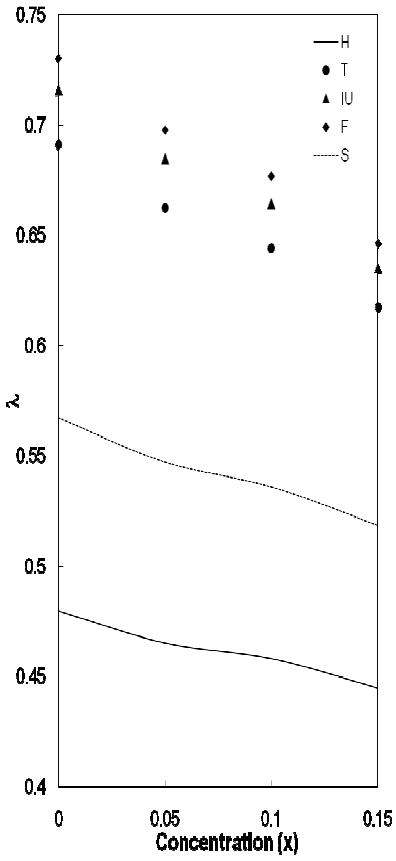


Fig.2: Variation of electron-phonon coupling strength ($\lambda$) with V-concentration $x$ (at %).

The computed values of the Coulomb pseudo-potential $\mu^*$, which accounts for Coulomb interaction between the conduction electrons, obtained from the various forms of local field correction functions are tabulated in Table 2 along with other theoretical data [11]. It is observed that for $(Ni_{33}Zr_{67})_{1-x}M_x$ ($x=$ 0, 0.05, 0.1, 0.15, $M=V$) ternary amorphous superconductors, $\mu^*$ lies between 0.14 and 0.16. This is in accordance with McMillan [13], who suggested $\mu^* \approx 0.13$ for transition metals. The graphs of $\mu^*$ versus the concentration, $x$, for different local field correction functions are plotted in Figure 3, which shows the weak dependence of $\mu^*$ on the local field correction functions. The weak screening influence shows up in the computed values of $\mu^*$. The percentile influence of the various local field correction functions with respect to the static H-screening function on $\mu^*$ for superconductors is observed in the range of 4.97%-10.66% for $(Ni_{33}Zr_{67})_{1-x}M_x$ ($x=$ 0, 0.05, 0.1, 0.15, $M=V$), respectively. The present results are found in good agreement with the available theoretical data [11].

Table 2 contains calculated values of the transition temperature $T_C$ for $(Ni_{33}Zr_{67})_{1-x}M_x$ ($x=$ 0, 0.05, 0.1, 0.15, $M=V$) ternary amorphous superconductors computed from the various forms of the local field correction functions along with theoretical [11] and experimental [4] findings. The present results obtained from the S-local field correction functions are found in good agreement with the available theoretical [11] and experimental [4] data. The calculated results of the transition temperature $T_C$ for $(Ni_{33}Zr_{67})_{1-x}M_x$ ($x=$ 0, 0.05, 0.1, 0.15, $M=V$) ternary amorphous superconductors deviate in the range of 0.02%-148.80% from the experimental findings [4]. The variation of the computed values of transition temperature $T_C$ for $(Ni_{33}Zr_{67})_{1-x}M_x$ ($x=$ 0, 0.05, 0.1, 0.15, $M=V$) ternary amorphous superconductors with the atomic concentration ($x$)

of **'**V**',** using five different types of the local field correction functions with EMC potential are shown in Fig. 4. The graph also includes the experimental findings [4]. It is seen that $T_C$ is quite sensitive to the local field correction functions and the results of $T_C$ by using S-screening are in best agreement with experimental data [4] for the $(Ni_{33}Zr_{67})_{1-x}M_x$ ($x$= 0, 0.05, 0.1, 0.15, $M=V$) ternary amorphous superconductors under investigation, as the relevant curves for S-screening almost overlap theoretical curves. It can also be seen from the graph that $T_C$ decreases considerably with increasing V-concentration ($x$). The composition dependence can be described by polynomial regression of the data obtained for S-screening for different values of the concentration '$x$', which yields

$$T_C(K) = 14x^2 - 7.78x + 2.661 \qquad (18)$$

The graph of the fitted $T_C$ equation is displayed in Fig. 4, which indicates that $T_C$ decreases considerably with increasing 'Ti' content with slope given as $dT_C/dx = 7.78$. Wide extrapolation predicts a $T_C = 2.661$K for the hypothetical case of 'amorphous pure $Ni_{33}Zr_{67}$' alloy. This quadratic relation is found in qualitative agreement with those given by Sharma et al. [11].

The presently computed values of the $T_C$ are found in the range that is suitable for further exploration of applications of the superconductors for usage like lossless transmission line for cryogenic applications. While alloying elements show good elasticity and could be drawn in the form of wires, as such they have good chances of being used as superconducting transmission lines at low temperature of the order of 7K.

The values of the isotope effect exponent $\alpha$ for $(Ni_{33}Zr_{67})_{1-x}M_x$ ($x$= 0, 0.05, 0.1, 0.15, $M=V$) ternary amorphous superconductors are tabulated in

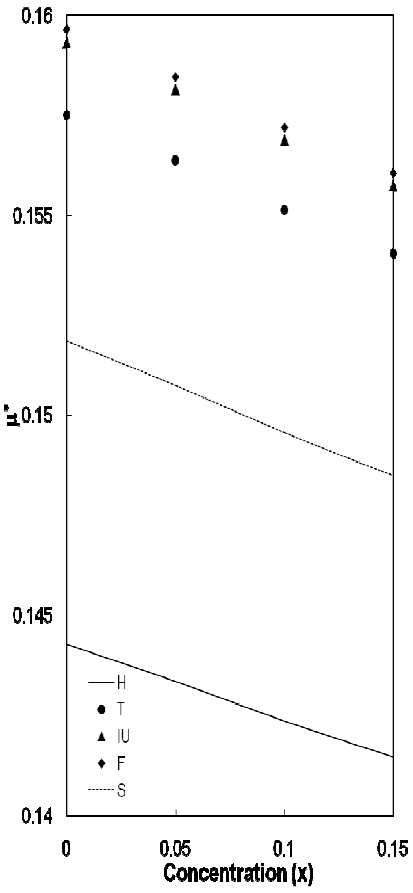


Fig.3: Variation of Coulomb pseudo-potential ($\mu^*$) with V-concentration $x$ (at %).

Table 2. Fig. 5 depicts the variation of $\alpha$ with V-concentration $x$ decreases. The computed values of $\alpha$ show a weak dependence on the dielectric screening function. Since the experimental value of $\alpha$ has not been reported in the literature so far, the present data for $\alpha$ may be used for the study of ionic vibrations in the superconductivity of alloying substances. Since S-local field correction function yields the best results for $\lambda$ and $T_C$, it may be observed that $\alpha$ values obtained from this screening provide the best account for the role of the ionic vibrations in superconducting behaviour of this system.

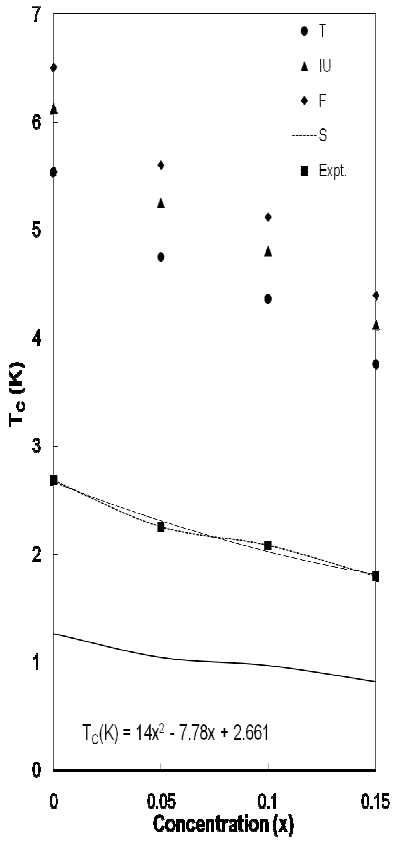


Fig.4: Variation of transition temperature ($T_C$) with V-concentration $x$ (at %).

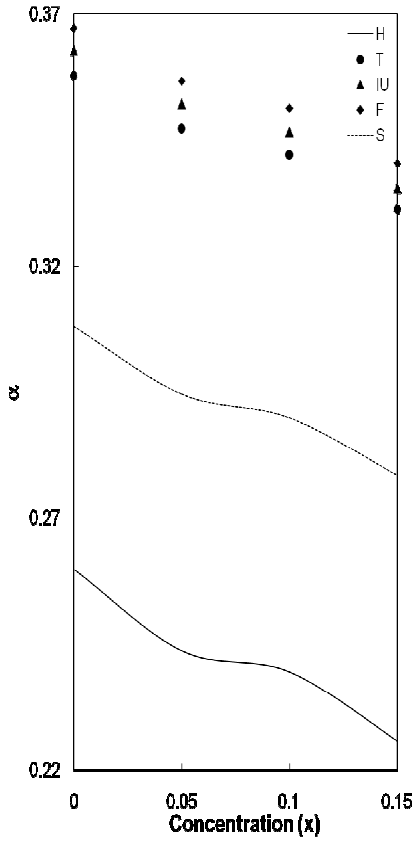


Fig.5: Variation of isotope effect exponent $(\alpha)$ with V-concentration $x$ (at %).

The values of effective interaction strength $N_O V$ are listed in Table 2 and depicted in Fig. 6 for different local field correction functions. It is observed that the magnitude of $N_O V$ shows that $(Ni_{33}Zr_{67})_{1-x}M_x$ ($x$= 0, 0.05, 0.1, 0.15, $M = V$) ternary amorphous superconductors under investigation lie in the range of weak to intermediate superconductors.

On the basis of Ichimaru-Utsumi local field correction function [17], Farid et al. [18] and Sarkar et al. [19] have given a local field correction function. Hence, Ichimaru-Utsumi and Farid et al. functions represent same characteristic nature. Also, the superconducting state parameters computed from Sarkar et al. local field correction are found in qualitative agreement with available theoretical data [11].

The effect of local field correction functions played an important role in the computation of $\lambda$ and $\mu^*$, which makes drastic variation on $T_C$, $\alpha$ and $N_O V$. The local field correction functions due to IU, F and S are able to generate consistent results regarding the superconducting state parameters of $(Ni_{33}Zr_{67})_{1-x}M_x$ ($x$= 0, 0.05, 0.1, 0.15, $M = V$) ternary amorphous superconductors as those obtained from more commonly employed Hartree and Taylor functions. The computed results of $\alpha$ and $N_O V$ are not showing any abnormal values for the $(Ni_{33}Zr_{67})_{1-x}M_x$ ($x$= 0, 0.05, 0.1, 0.15, $M = V$) ternary amorphous superconductors.

From the overall study of the superconducting properties, one can be observed that, the Hartree screening function [15] yields lowest values, whereas the values obtained from the Farid et al. [18] function are the highest, which suggested that in the present case, the Sarkar et al. screening function [19] is suites more than the other screening functions. Thus, the use of these more promising local field correction functions is established successfully. Also, the Hartree screening function [15] does not included exchange and correlation effects in contrast to other functions. After introducing the screening effects in the pseudo-potential, the results of the SSP are

more affected due to the nature of the local field correction functions.

This simple methodology successfully explains superconducting behavior of ternary amorphous superconductors without requiring the solution of Dirac equation for many body problem or an estimation of various interactions as required in pseudo-potential theory. We have determined the superconducting properties of ternary amorphous superconductors in the BCS-Eliashberg-McMillan framework. We noted that the addition of 'V' as the third element ( $M$ ) to a binary metallic systems ($Ni_{33}Zr_{67}$) causes parameters $\lambda$, $T_C$, $\alpha$, and $N_O V$ to decrease, and the Coulomb pseudo-potential ( $\mu^*$ ) to increase with the concentration of the third element. This shows that the presence of the third element causes suppression of superconducting behaviour of the alloy. The decrease in $T_C$ with increasing concentration of third element ( $M$ ) may be attributed to modifications in the density of states at Fermi level $N(E_F)$ and probable changes in the band structure of the alloy [11]. Both specific heat measurements and band structure calculation [1-4] reveal a decrease in density of states at $E_F$ with the addition of third element. Since, $T_C$ is related to the modifications of density of states at $E_F$, $N(E_F)$, a decrease in $T_C$ can be related to the modifications of DOS at the Fermi level, $N(E_F)$ [11].

It is also observed that superconductivity persists only for small values of $x$ (i.e., $x \le 0.15$ ). This is because the third element considered here are all 3d-transition metals which have smaller band width and stronger localized character than Zr, thus causing a narrowing of bands in ternary system [11]. These narrow bands have magnetic instabilities which prevent superconductivity as suggested by Allen and Dynes [26].

According to Matthias rules [27, 28], the ternary amorphous superconductors having Z>2 do exhibit superconducting nature. Hence, $(Ni_{33}Zr_{67})_{1-x}M_x$ ( $x =$ 0, 0.05, 0.1, 0.15, $M = V$ ) ternary amorphous superconductors are exhibiting superconducting nature in the present case. When we go from Z=3.34 to Z=3.59, the electron-phonon coupling strength $\lambda$ changes with lattice spacing "a". Similar trends are also observed in the values of $T_C$ for all ternary amorphous superconductors. Hence, a strong dependency of the superconducting state parameters of the ternary amorphous superconductors on the valence ' $Z$ ' is found.

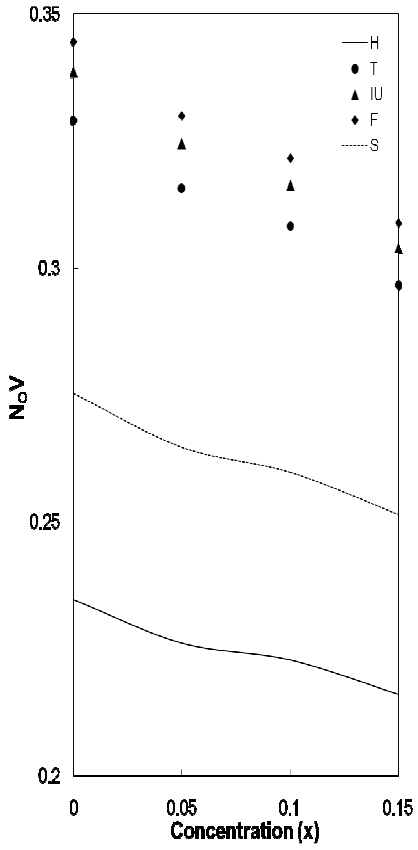


Fig.6: Variation of effective interaction strength ( $N_O V$ ) with V-concentration $x$ (at %).

Lastly, we would like to emphasize the importance of involving a precise form for the pseudo-potential. It must be confessed that although the effect of pseudo-potential in strong coupling superconductor is large, yet it plays a decisive role in weak coupling superconductors i.e., those substances which are at the boundary dividing the superconducting and non-superconducting regions. In other words, a small variation in the value of electron-ion interaction may lead to an abrupt change in the superconducting properties of the material under consideration. In this connection, we may realize the importance of an accurate form for the pseudopotential.

## 4. Conclusions

The H-local field corrections when used with EMC model potential provide the best explanation for superconductivity in $(Ni_{33}Zr_{67})_{1-x}M_x$ ( $x =$ 0, 0.05, 0.1, 0.15, $M = V$ ) ternary amorphous superconductors. The values of $\lambda$ and $T_C$ show an

appreciable dependence on the local field correction function, whereas for $\mu^*$, $\alpha$ and $N_O V$ a weak dependence is observed. The magnitude of $\lambda$, $\alpha$ and $N_O V$ values shows that the ternary amorphous alloys are weak to intermediate superconductors. Quadratic $T_C$ equation has been proposed, which provides successfully the $T_C$ values of the ternary amorphous alloys under consideration. In the absence of experimental data for $\alpha$ and $N_O V$, the presently computed values may be considered to form reliable data for these ternary systems, as they lie within the theoretical limits of the Eliashberg-McMillan formulation. The comparisons of presently computed results of the superconducting state parameters (SSP) of the $\left(Ni_{33}Zr_{67}\right)_{1-x}M_x$ ($x = 0,\ 0.05,\ 0.1,\ 0.15,\ M = V$) ternary amorphous superconductors with available experimental findings are highly encouraging, which confirms the applicability of the EMC model potential and different forms of the local field correction functions. Such study on superconducting state parameters of other multi component metallic alloys is in progress.

## References


[1] U. Mizutani, C. Mishima and T. Goto, J. Phys. Cond. Matter **1**, 1831 (1989).

[2] R. Zehringer, P. Oelhafen, H.-J. Guntherodt, Y. Yamada and U. Mizutani, Mater. Sci. Engg. **99**, 317 (1988).

[3] U. Mizutani, U. Mizutani and C. Mishima, Solid State Commun. **62**, 641 (1987).

[4] Y. Yamada, Y. Itoh and U. Mizutani, Mater. Sci. Engg. **99**, 289 (1988).

[5] A. V. Narlikar and S. N. Ekbote, *Superconductivity and Superconducting Materials* (South Asian Publishers, New Delhi, Madras, 1983).

[6] Aditya M. Vora, Armenian J. Phys. **2**, 213 (2009).

[7] Aditya M. Vora, M. J. Condensed Matter **10**, 15 (2008).

[8] Aditya M. Vora, Sci. Technol. Adv. Mater. **9**, 025017 (2008).

[9] Aditya M. Vora, Physica C **468**, 937, 2292 (2008).

[10] Aditya M. Vora, Chin. Phys. Lett. **27**, 026102-1 (2010).

[11] S. Sharma, H. Khan and K. S. Sharma, Czech. J. Phys. **55**, 1005 (2005).

[12] P. Chatterjee, Can. J. Phys. **58**, 1383 (1980).

[13] W. L. McMillan, Phys. Rev. **167**, 331 (1968).

[14] N. W. Ashcroft, Phys. Lett. **23**, 48 (1966).

[15] W. A. Harrison, *Elementary Electronic Structure* (World Scientific, Singapore, 1999).

[16] R. Taylor, J. Phys. F: Met. Phys. **8**, 1699 (1978).

[17] S. Ichimaru and K. Utsumi, Phys. Rev. **B24**, 7386 (1981).

[18] B. Farid, V. Heine, G. Engel and I. J. Robertson, Phys. Rev. **B48**, 11602 (1993).

[19] A. Sarkar, D. Sen, H. Haldar and D. Roy, Mod. Phys. Lett. **B12**, 639 (1998).

[20] W. H. Butler, Phys. Rev. **B15**, 5267 (1977).

[21] J. J. Hopfield, Phys. Rev. **186**, 443 (1969).

[22] G. D. Gaspari and B. L. Gyorff, Phys. Rev. Lett. **28**, 801 (1972).

[23] N. P. Kovalenko, Yu. P. Krasny and U. Krey, *Physics of Amorphous Metals* (Wiley-VCH, Berlin, 2001).

[24] P. Moral and P. W. Anderson, Phys. Rev. **125**, 1263 (1962).

[25] J. S. Rajput and A. K. Gupta, Phys. Rev. **181**, 743 (1969).

[26] P. B. Allen and M. L. Cohen, Phys. Rev. **187**, 525 (1969).

[27] B. T. Matthias, *Progress in Low Temperature Physics*, Ed. C. J. Gorter (North Holland, Amsterdam, 1957), Vol. 2.

[28] B. T. Matthias, Physica **69**, 54 (1973).


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