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Superconducting state parameters of binary metallic glasses

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ABSTRACT

Well known Ashcroft's empty core (EMC) model potential is used to study the theoretical investigation of the superconducting state parameters (SSP) viz. electron-phonon coupling strength, Coulomb pseudopotential, transition temperature, isotope effect exponent and effective interaction strength of some binary metallic glasses. More advanced screening function due to Farid *et al.* (F) has been employed to include the exchange and correlation effect on the aforesaid properties. The present results are found in qualitative agreement with other such earlier reported data available in the literature, which confirm the superconducting phase in the binary metallic glasses. Copyright © 2012 VBRI Press.

Keywords: Pseudopotential; superconducting state parameters; binary metallic glasses; local field correction function.

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Introduction

During last several years, the superconductivity remains a dynamic area of research in condensed matter physics with continual discoveries of novel materials and with an increasing demand for novel devices for sophisticated technological applications. A large number of metals and amorphous alloys are superconductors, with critical temperature T_C ranging from 1-18K. The pseudopotential theory has been used successfully in explaining the superconducting state parameters (SSP) for metallic complexes by many workers **[1-23].** Many of them have used well known model pseudopotential in the calculation of the superconducting state parameters for the metallic complexes **[4-22].** Out of very large numbers of metallic glasses, the SSP of only few metallic glasses are reported based on the pseudopotential, so far. Recently, we have studied the superconducting state parameters of some metallic superconductors using single parametric model potential formalism **[4-15].** The study of the superconducting state parameters of the metallic superconductors such as metals, alloys and metallic glasses may be of great help in deciding their applications; the study of the dependence of the transition temperature T_c on the composition of metallic elements is helpful in finding new superconductors with high T_c. The application of pseudopotential to binary metallic superconductors involves the assumption of pseudoions with average properties, which are assumed to replace three types of ions in the binary systems, and a gas of free electrons is assumed to permeate through them. The electron-pseudoion is accounted for by the pseudopotential and the electron-electron interaction is involved through a dielectric screening function. For successful prediction of the superconducting properties of the alloying systems, the proper selection of the pseudopotential and screening function is very essential **[4-15].**

Therefore, in the present article, we have used well known McMillan's theory **[23]** of the superconductivity for predicting the superconducting state parameters viz. the electron-phonon coupling strength λ, Coulomb pseudopotential μ* transition temperature T_c, isotope effect exponent α and effective interaction strength N_oV of some binary metallic glasses based on the superconducting (S), conditional superconducting (S') and non-superconducting (NS) elements of the periodic table using model potential formalism. To see the impact of various exchange and correlation function on the aforesaid properties, we have employed for the first time more advanced local field correction function proposed by Farid *et al.* (F) **[24]** with

Ashcroft's empty core (EMC) model potential **[25]** in the present computation.

In most of the theoretical studies of superconductivity of bulk metallic complexes, the Vegard's law was used to calculate electron-ion interaction from the potential of the pure components. Also in bulk metallic glasses, the translational symmetry is broken, and therefore, the momentum (or quasi-momentum) should not be used to describe the state of the system. The virtual crystal approximation enables us to keep the concept of the momentum only in an approximate way. But, it is well established that pseudo-alloy-atom (PAA) is more meaningful approach to explain such kind of interactions in binary systems **[4-15]**. In the PAA approach a hypothetical monoatomic crystal is supposed to be composed of pseudo-alloy-atoms, which occupy the lattice sites and from 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 pseudopotential theory is then applied to studying various properties of alloy systems. The complete miscibility in the glassy alloy systems is considered as a rare case. Therefore, in such binary 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 **[4-15].**

The well-known Ashcroft's empty core (EMC) model potential **[25]** used in the present computations of the SSP of metals is of the form,

$$V(q) = \frac{-8\pi Z}{\Omega_O q^2}\cos(qr_C) \qquad (1)$$

here, Z, Ω_O and r_C are the valence, atomic volume and parameter of the model potential of metals, respectively. The Ashcroft's empty core (EMC) model potential is a simple one-parameter model potential, which has been successfully found for various metallic complexes **[4-22].** When used with a suitable form of dialectic screening functions, this potential has also been found to yield good results in computing the SSP of metallic elements **[4-22].** Here, the model potential parameter r_C is fitted in such a way that the calculated values of the transition temperature T_C agrees well with the theoretical or experimental value of the T_C as close as possible.

Computational methodology

In the present investigation for binary metallic glasses, the electron-phonon coupling strength λ is computed using the relation **[4-23]**

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

here m_b is the band mass, M the ionic mass, Ω_O the atomic volume, k_F the Fermi wave vector, $V(q)$ the screened pseudopotential and $\langle\omega^2\rangle$ the averaged square phonon frequency, of the binary glassy alloy, respectively. The effective averaged square phonon frequency $\langle\omega^2\rangle$ is calculated using the relation given by Butler [**26**], $\langle\omega^2\rangle^{1/2} = 0.69\,\theta_D$, where θ_D is the Debye temperature of the binary metallic glasses.

Table 1. Input parameters and other constants.

Metallic glass	Valence	Potential Parameter	Atomic Volume	Atomic Mass	Debye Temperate
$Au_{84}Si_{16}$	1.48	0.3688	116.58	169.95	241.80
$Mg_{85.5}Cu_{14.5}$	1.84	1.6111	132.28	29.99	349.77
$Ca_{70}Mg_{30}$	2.00	2.2645	252.14	35.35	282.00
$Ca_{70}Zn_{30}$	2.00	2.2578	261.28	47.67	286.09
$Mg_{70}Zn_{30}$	2.00	1.6348	133.22	36.63	344.59
$Mg_{84}Ni_{16}$	2.00	1.5189	128.44	29.81	440.73
$Cu_{66}Ti_{34}$	2.02	1.8073	92.33	58.23	365.80
$Be_{90}Al_{10}$	2.10	1.6203	60.09	10.81	1338.80
$Cu_{60}Zr_{40}$	2.20	1.5006	110.71	74.62	322.20
$Ni_{81}B_{19}$	2.20	1.5103	69.79	49.61	787.60
$Be_{70}Al_{30}$	2.30	0.4721	71.47	14.40	1136.40
$Cd_{90}Ge_{10}$	2.30	0.9564	145.50	108.43	225.50
$Cu_{33}Y_{67}$	2.34	1.7099	175.41	80.54	317.76
$Cu_{55}Zr_{45}$	2.35	0.9187	114.59	76.00	319.60
$Ca_{60}Al_{40}$	2.40	2.1125	220.60	34.84	303.77
$Cu_{50}Zr_{50}$	2.50	1.4564	118.47	77.39	317.00
$La_{80}Au_{20}$	2.60	1.7892	224.40	150.52	146.60
$Cu_{45}Zr_{55}$	2.65	1.4320	122.34	78.77	314.40
$Ni_{33}Y_{67}$	2.67	1.6487	173.77	78.94	364.72
$Ni_{31}Dy_{69}$	2.69	0.9774	163.79	130.22	309.54
$Cu_{43}Ti_{57}$	2.71	1.5473	101.18	54.63	370.56
$Cu_{40}Zr_{60}$	2.80	1.4149	126.22	80.15	311.80
$Cu_{35}Zr_{65}$	2.95	0.9277	130.10	81.54	309.20
$Cu_{60}W_{40}$	3.00	1.4312	90.47	111.67	300.79
$Fe_{80}B_{20}$	3.00	1.3421	71.04	46.84	457.00
$Fe_{83}B_{17}$	3.00	1.3451	73.13	48.19	599.00
$La_{80}Ga_{20}$	3.00	1.6840	228.04	125.08	177.60
$Ni_{50}Zr_{50}$	3.00	0.7656	115.52	74.96	370.50
$Cu_{33}Zr_{67}$	3.01	0.9307	131.65	82.09	308.16
$Cu_{57}Zr_{43}$	3.01	1.5935	160.20	82.09	322.89
$Cu_{30}Zr_{70}$	3.10	0.9296	133.98	82.92	306.60
$Fe_{90}Zr_{10}$	3.10	1.3979	86.99	59.39	436.80
$Ni_{60}Nb_{40}$	3.20	0.6735	92.98	72.38	317.67
$Pd_{80}Si_{20}$	3.20	0.7099	106.66	70.74	266.00
$Cu_{25}Zr_{75}$	3.25	0.9355	137.86	84.30	304.00
$Ni_{36}Zr_{64}$	3.28	0.7696	127.06	74.51	367.32
$Tl_{90}Te_{10}$	3.30	0.8618	195.28	196.69	85.95
$Co_{67}Zr_{33}$	3.33	1.4376	102.59	69.59	323.11
$Zr_{67}Ni_{33}$	3.34	1.4848	129.59	80.49	372.53
$Fe_{80}P_{20}$	3.40	1.3192	80.34	50.87	671.16
$In_{80}Sb_{20}$	3.40	1.7078	181.04	116.21	128.60
$Zr_{70}Be_{30}$	3.40	1.7350	126.22	66.56	635.70
$Zr_{70}Pd_{30}$	3.40	1.2967	139.69	95.77	285.90
$Zr_{70}Co_{30}$	3.40	1.1410	81.53	127.93	337.20
$Pd_{35}Zr_{65}$	3.65	1.7147	265.78	96.53	279.61
$Pb_{90}Cu_{10}$	3.70	1.3713	203.98	192.83	128.80

$Sn_{90}Cu_{10}$	3.70	1.3469	171.24	113.18	214.30
$Zr_{75}Rh_{25}$	3.75	1.3567	140.90	94.14	338.25
$Pb_{75}Bi_{25}$	4.25	1.7684	212.40	207.64	108.50
$Pb_{50}Bi_{50}$	4.50	1.7501	221.40	208.09	112.00

Table 2. Electron-phonon coupling strength (λ) of binary metallic glasses.

Metallic glass	**Present**	**Expt. [2, 28]**	**Others [4-22]**
$Au_{84}Si_{16}$	0.5670	–	0.6332
$Mg_{85.5}Cu_{14.5}$	0.4752	–	0.5376
$Ca_{70}Mg_{30}$	0.8353	–	0.89, 0.83, 1.07, 1.26, 1.26,1.31, 1.75, 1.82, 2.04
$Ca_{70}Zn_{30}$	0.5546	–	0.5823
$Mg_{70}Zn_{30}$	0.5450	0.30	0.501,0.33, 0.48, 0.48, 0.61
$Mg_{84}Ni_{16}$	0.3295	–	0.3912
$Cu_{66}Ti_{34}$	0.8956	–	1.0274
$Be_{90}Al_{10}$	0.5847	–	0.7820, 0.644, 0.644, 0.643
$Cu_{60}Zr_{40}$	0.4307	–	0.436, 0.402, 0.394, 0.3908, 0.3852
$Ni_{81}B_{19}$	0.2729	–	0.3602
$Be_{70}Al_{30}$	0.7207	–	0.761, 0.616, 0.614, 0.613
$Cd_{90}Ge_{10}$	0.5666	–	0.6447
$Cu_{33}Y_{67}$	0.3190	–	0.3738
$Cu_{55}Zr_{45}$	0.4614	–	0.4746,0.4387, 0.4297, 0.4259, 0.4199
$Ca_{60}Al_{40}$	1.2462	–	1.3571
$Cu_{50}Zr_{50}$	0.4913	–	0.4973,0.4603, 0.4498, 0.4459, 0.4396
$La_{80}Au_{20}$	0.7954	–	0.8512
$Cu_{45}Zr_{55}$	0.5141	–	0.520,0.482,0.470, 0.466,0.4596
$Ni_{33}Y_{67}$	0.3279	–	0.6914
$Ni_{31}Dy_{69}$	0.2754	–	0.3580
$Cu_{43}Ti_{57}$	1.1124	–	1.2836
$Cu_{40}Zr_{60}$	0.5445	–	0.550, 0.510,0.497, 0.493,0.486
$Cu_{35}Zr_{65}$	0.5618	–	0.576, 0.536,0.521, 0.5175,0.510
$Cu_{60}W_{40}$	1.0448	–	1.2031
$Fe_{80}B_{20}$	1.3589	–	1.6168
$Fe_{83}B_{17}$	0.7349	–	0.8987
$La_{80}Ga_{20}$	0.7672	–	0.8335
$Ni_{50}Zr_{50}$	0.7258	–	0.8574
$Cu_{33}Zr_{67}$	0.5681	–	0.583,0.542, 0.527, 0.523, 0.516
$Cu_{57}Zr_{43}$	0.6026	–	0.6911
$Cu_{30}Zr_{70}$	0.5873	–	0.474,0.438, 0.429, 0.425, 0.419
$Fe_{90}Zr_{10}$	1.0164	–	1.1986
$Ni_{60}Nb_{40}$	1.5220	–	1.7884
$Pd_{80}Si_{20}$	1.9329	–	2.2570
$Cu_{25}Zr_{75}$	0.6055	–	0.619,0.578, 0.560, 0.556,0.548
$Ni_{36}Zr_{64}$	0.8016	–	0.9430
$Tl_{90}Te_{10}$	1.0085	1.7	1.9728, 0.77,0.84
$Co_{67}Zr_{33}$	1.5736	–	1.8213
$Zr_{67}Ni_{33}$	0.7400	–	0.8604
$Fe_{80}P_{20}$	0.6243	–	0.7854
$In_{80}Sb_{20}$	0.9773	1.7	1.770, 0.80,1.00
$Zr_{70}Be_{30}$	0.5432	–	0.6837
$Zr_{70}Pd_{30}$	0.5793	–	0.6723
$Zr_{70}Co_{30}$	0.5764	–	–
$Pd_{35}Zr_{65}$	0.5774	–	0.6462
$Pb_{90}Cu_{10}$	1.0554	2.0	1.1531
$Sn_{90}Cu_{10}$	0.8548	1.84	1.8402
$Zr_{75}Rh_{25}$	0.6534	–	0.7615
$Pb_{75}Bi_{25}$	1.2108	2.76	2.7603,1.08,1.33
$Pb_{50}Bi_{50}$	1.1949	–	1.9138

Using $X = q/2k_F$ and $\Omega_O = 3\pi^2 Z/(k_F)^3$, we get **Eq. (2)** in the following form,

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

where Z and $W(X)$ are the valence of the binary metallic glasses and the PAA screened EMC pseudopotential **[26]** for binary mixture, respectively.

The Coulomb pseudopotential μ^* is given by **[4-24]**

$$\mu^* = \frac{\frac{m_b}{\pi k_F} \int_0^1 \frac{dX}{\varepsilon(X)}}{1 + \frac{m_b}{\pi k_F} \ln\left(\frac{E_F}{10\,\theta_D}\right) \int_0^1 \frac{dX}{\varepsilon(X)}} \qquad (4)$$

where E_F is the Fermi energy, m_b the band mass of the electron, θ_D the Debye temperature and $\varepsilon(X)$ the modified Hartree dielectric function, which is written as **[4-15]**

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

here $\varepsilon_H(X)$ is the static Hartree dielectric function **[27]** and the expression of $\varepsilon_H(X)$ is given by,

$$\varepsilon_H(X) = 1 + \frac{me^2}{2\pi k_F \hbar^2 \eta^2}\left(\frac{1-\eta^2}{2\eta} \ln\left|\frac{1+\eta}{1-\eta}\right| + 1\right); \eta = \frac{q}{2k_F} \qquad (6)$$

While $f(X)$ is the local field correction function. In the present investigation, the local field correction function due to Farid *et al.* (F) [**24**] is incorporated to see the impact of exchange and correlation effects. The details of all the local field corrections are below.

Farid *et al.* (F) **[24]** have given a local field correction function of the form

$$f(X) = A_F Q^4 + B_F Q^2 + C_F + \left[A_F Q^4 + D_F Q^2 - C_F\right]\left\{\frac{4-Q^2}{4Q} \ln\left|\frac{2+Q}{2-Q}\right|\right\} \qquad (7)$$

where $Q = 2X$. The parameters A_F, B_F, C_F and D_F are the atomic volume dependent parameters F-local field correction function. The mathematical expressions of these parameters are narrated in the respective paper of the local field correction function **[24].**

Table 3. Coulomb pseudopotential (μ^*) of binary metallic glasses.

Metallic glass	Present	Others [4-22]
$Au_{84}Si_{16}$	0.1637	0.1995
$Mg_{85.5}Cu_{14.5}$	0.1708	0.2138
$Ca_{70}Mg_{30}$	0.1854	0.2130,0.14,0.14,0.15, 0.16, 0.18, 0.19
$Ca_{70}Zn_{30}$	0.1873	0.2142
$Mg_{70}Zn_{30}$	0.1677	0.2178,0.12,0.14, 0.16, 0.17
$Mg_{84}Ni_{16}$	0.1735	0.2227
$Cu_{66}Ti_{34}$	0.1567	0.2979
$Be_{90}Al_{10}$	0.1753	0.2694,0.191,0.191, 0.191
$Cu_{60}Zr_{40}$	0.1567	0.1486, 0.1439, 0.1398, 0.1384, 0.1369
$Ni_{81}B_{19}$	0.1640	0.2382
$Be_{70}Al_{30}$	0.1737	0.2604,0.166,0.166, 0.166
$Cd_{90}Ge_{10}$	0.1550	0.1936
$Cu_{33}Y_{67}$	0.1696	0.2102
$Cu_{55}Zr_{45}$	0.1555	0.1473,0.1428,0.1387, 0.1373 , 0.1359
$Ca_{60}Al_{40}$	0.1756	0.2115
$Cu_{50}Zr_{50}$	0.1544	0.1461,0.1417,0.1375 , 0.1363, 0.1359
$La_{80}Au_{20}$	0.1539	0.1825
$Cu_{45}Zr_{55}$	0.1534	0.1449,0.1406,0.1365, 0.1353, 0.1340
$Ni_{33}Y_{67}$	0.1685	0.5140
$Ni_{31}Dy_{69}$	0.1618	0.2056
$Cu_{43}Ti_{57}$	0.1508	0.2048
$Cu_{40}Zr_{60}$	0.1525	0.1437,0.1395, 0.1354 , 0.1343,0.1330
$Cu_{35}Zr_{65}$	0.1516	0.1425, 0.1385,0.1344, 0.1334, 0.1321
$Cu_{60}W_{40}$	0.1403	0.1930
$Fe_{80}B_{20}$	0.1420	0.2053
$Fe_{83}B_{17}$	0.1486	0.2180
$La_{80}Ga_{20}$	0.1547	0.1874
$Ni_{50}Zr_{50}$	0.1517	0.2054
$Cu_{33}Zr_{67}$	0.1513	0.1420,0.1381, 0.1340, 0.1330, 0.1321
$Cu_{57}Zr_{43}$	0.1585	0.2052
$Cu_{30}Zr_{70}$	0.1508	0.1414,0.1375,0.1334 , 0.1324, 0.1312
$Fe_{90}Zr_{10}$	0.1459	0.2066
$Ni_{60}Nb_{40}$	0.1404	0.1944
$Pd_{80}Si_{20}$	0.1405	0.1901
$Cu_{25}Zr_{75}$	0.1501	0.1402,0.1365,0.1324, 0.1315, 0.1303
$Ni_{36}Zr_{64}$	0.1517	0.2051
$Tl_{90}Te_{10}$	0.1333	0.1624, 0.11, 0.11
$Co_{67}Zr_{33}$	0.1423	0.1960
$Zr_{67}Ni_{33}$	0.1521	0.2057
$Fe_{80}P_{20}$	0.1501	0.2228
$In_{80}Sb_{20}$	0.1383	0.1726,0.12,0.12
$Zr_{70}Be_{30}$	0.1639	0.2302
$Zr_{70}Pd_{30}$	0.1478	0.1960
$Zr_{70}Co_{30}$	0.1365	–
$Pd_{35}Zr_{65}$	0.1650	0.2042
$Pb_{90}Cu_{10}$	0.1392	0.1730
$Sn_{90}Cu_{10}$	0.1449	0.1873
$Zr_{75}Rh_{25}$	0.1489	0.2012
$Pb_{75}Bi_{25}$	0.1337	0.1669,0.11,0.12
$Pb_{50}Bi_{50}$	0.1339	0.1677

After evaluating λ and μ^*, the transition temperature T_C and isotope effect exponent α are investigated from the McMillan's formula **[4-23]**

$$T_C = \frac{\theta_D}{1.45}\exp\left[\frac{-1.04(1+\lambda)}{\lambda-\mu^*(1+0.62\lambda)}\right] \quad (8)$$

$$\alpha = \frac{1}{2}\left[1-\left(\mu^* \ln\frac{\theta_D}{1.45T_C}\right)^2 \frac{1+0.62\lambda}{1.04(1+\lambda)}\right] \quad (9)$$

The expression for the effective interaction strength $N_O V$ is studied using **[4-22]**

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

Results and discussion

The input parameters are other constants used in the present computation of the SSP of fifty metallic glasses are shown in **Table 1**. To determine the input parameters and various constants for PAA model, the following definitions for binary metallic glasses ($A_{1-X}B_X$) are adopted **[4-15]**,

$$Z = (1-X)(Z_A) + X(Z_B) \quad (11)$$

$$M = (1-X)(M_A) + X(M_B) \quad (12)$$

$$\Omega_O = (1-X)(\Omega_{OA}) + X(\Omega_{OB}) \quad (13)$$

$$\theta_D = (1-X)(\theta_{DA}) + X(\theta_{DB}) \quad (14)$$

where 'X' is the concentration factor of the second metallic component. The graphical representation of the model potential parameter and input parameters with valence are displayed in **Fig. 1-2**.

In the present work, we used $m_b = 1$ for the sake of uniformity. The presently calculated superconductor state parameters of binary metallic glasses are tabulated in **Table 2-6** with experimental **[2, 28-31]** and other such available theoretical **[4-22]** findings. The graphical nature of the superconductor state parameters with atomic concentration (X) of the second metallic component (in at %) and valance of the binary metallic glasses are displayed in **Fig. 3-5.**

The computed values of the electron-phonon coupling strength λ for binary metallic glasses are shown in **Table 2** with other such experimental **[2, 25]** and theoretical **[4-22]** data, which are found to be in good agreement with them. It is seen from **Table 2** that, the electron-phonon coupling strength $\lambda \leq 1$ for 46 binary metallic glasses while for 12 binary metallic glasses $\lambda > 1$. One can also observe that λ goes on increasing from the values of 0.3158→0.6055 as the concentration of 'Zr' increases from 0.40 to 0.75 in the series of Cu-Zr metallic glasses. Such increase in λ 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 Zr-with increasing concentration, as was also observed by Minnigerode and Samwer **[32].** This may also be attributed to the increase role of ionic vibrations in the Zr-rich region **[16-22]**.

The computed values of the Coulomb pseudopotential μ^*, which accounts for the Coulomb interaction between the conduction electrons are tabulated in **Table 3** with other such theoretical data **[4-22]**. It is observed that, the

values of μ^* for all binary metallic glasses lie between 0.12 and 0.19, which is in accordance with McMillan **[24],** who suggested $\mu^* \approx 0.13$ for transition metals. The weak screening influence shows on the computed values of the μ^*. The present results are found to be in good agreement with available theoretical data **[4-22]**. Here it is also seen that, as the concentration (X) of Cu (in at %) increases the present results of μ^* decreases. The experimental data of μ^* is not available in the literature.

Table 4. Transition temperature (T_C) of binary metallic glasses.

Metallic glass	Present	Expt. [2, 28-31]	Others [4-22]
$Au_{84}Si_{16}$	1.4970	–	1.4015
$Mg_{85.5}Cu_{14.5}$	0.5750	–	0.4291
$Ca_{70}Mg_{30}$	6.2006	–	5.8, 6.2, 10.9, 15.3, 17.3,17.3, 20.9, 21.7, 24.2
$Ca_{70}Zn_{30}$	0.9485	–	0.6875
$Mg_{70}Zn_{30}$	1.5825	1.4, 0.7, 0.11	1.4 , 0.096, 0.8, 1.2, 2.59
$Mg_{84}Ni_{16}$	0.0031	–	0.0010
$Cu_{66}Ti_{34}$	12.2584	–	11.727
$Be_{90}Al_{10}$	7.8691	7.2	7.214 , 7.24 , 7.56, 7.19
$Cu_{60}Zr_{40}$	0.3668	0.31	0.52,0.31, 0.31, 0.296, 0.2759
$Ni_{81}B_{19}$	0.0000	–	0.0000
$Be_{70}Al_{30}$	17.3195	6.1	6.1529, 6.12, 6.15, 6.11
$Cd_{90}Ge_{10}$	1.6241	1.6	1.6004
$Cu_{33}Y_{67}$	0.0016	–	0.0009
$Cu_{55}Zr_{45}$	0.6581	0.65	0.98,0.65, 0.63, 0.61, 0.574
$Ca_{60}Al_{40}$	17.2204	–	16.635
$Cu_{50}Zr_{50}$	1.0371	0.92	1.34, 0.92, 0.88, 0.86, 0.81
$La_{80}Au_{20}$	3.7257	3.5	3.50
$Cu_{45}Zr_{55}$	1.3902	1.25	1.747, 1.25, 1.18, 1.15, 1.09
$Ni_{33}Y_{67}$	0.0041	–	0.0025
$Ni_{31}Dy_{69}$	0.00004	–	0.0004
$Cu_{43}Ti_{57}$	19.7244	–	19.106
$Cu_{40}Zr_{60}$	1.9226	1.75	2.34, 1.75, 1.65, 1.61, 1.536
$Cu_{35}Zr_{65}$	2.2632	2.25	2.93, 2.25, 2.11, 2.07, 1.98
$Cu_{60}W_{40}$	15.1956	–	14.73
$Fe_{80}B_{20}$	33.6922	–	32.98
$Fe_{83}B_{17}$	12.7394	–	12.09
$La_{80}Ga_{20}$	4.0439	3.8	3.804
$Ni_{50}Zr_{50}$	7.3515	–	7.277
$Cu_{33}Zr_{67}$	2.3928	2.38	3.09, 2.39, 2.2, 2.19, 2.107
$Cu_{57}Zr_{43}$	2.9325	–	2.6834
$Cu_{30}Zr_{70}$	2.7929	2.78	2.53, 2.78, 2.6, 2.57, 2.46
$Fe_{90}Zr_{10}$	20.3739	–	19.70
$Ni_{60}Nb_{40}$	26.8349	–	26.72
$Pd_{80}Si_{20}$	28.0394	–	27.97
$Cu_{25}Zr_{75}$	3.1945	3.18	3.98,3.19, 2.97, 2.924, 2.812
$Ni_{36}Zr_{64}$	9.7121	–	9.6273
$Tl_{90}Te_{10}$	4.2377	4.2	8.7047, 3.07, 3.74
$Co_{67}Zr_{33}$	28.0917	–	27.562
$Zr_{67}Ni_{33}$	7.8175	–	7.3753
$Fe_{80}P_{20}$	7.9825	–	7.7548
$In_{80}Sb_{20}$	5.8249	5.6	11.464, 4.43, 6.63
$Zr_{70}Be_{30}$	3.0980	2.8	2.4001
$Zr_{70}Pd_{30}$	2.5697	2.4	2.4010
$Zr_{70}Co_{30}$	3.5173	3.3	–
$Pd_{35}Zr_{65}$	1.8576	–	1.6627
$Pb_{90}Cu_{10}$	6.6594	6.5	6.5010
$Sn_{90}Cu_{10}$	7.0179	6.76	18.982
$Zr_{75}Rh_{25}$	4.8593	4.55	4.5511
$Pb_{75}Bi_{25}$	7.1085	6.91	13.742, 6.83, 8.73
$Pb_{50}Bi_{50}$	7.1966	6.99	10.844

Table 4 contains calculated values of the transition temperature T_C for binary metallic glasses along with experimental **[2, 28-31]** and theoretical **[4-22]** findings. The present results are found in good agreement with them. Also, the above results indicate that simple metallic glasses having low valance of one or two tend to have low T_C value, while those involving high valence (more than three) tend to have higher T_C value. Perhaps only exceptions are seen in divalent Be-based metallic glasses where high T_C is likely to be due to unusually high Debye temperature.

Table 5. Isotope effect exponent (α) of binary metallic glasses.

Metallic glass	Present	Others [4-22]
$Au_{84}Si_{16}$	0.253	0.1274
$Mg_{85.5}Cu_{14.5}$	0.051	-0.2638
$Ca_{70}Mg_{30}$	0.338	0.28,0.36,0.39,0.45, 0.46,0.46, 0.52
$Ca_{70}Zn_{30}$	0.085	-0.1078
$Mg_{70}Zn_{30}$	0.206	0.14,0.1,0.19, 0.23, 0.28
$Mg_{84}Ni_{16}$	-1.228	-2.9043
$Cu_{66}Ti_{34}$	0.411	0.3421
$Be_{90}Al_{10}$	0.212	-0.1844, 0.192, 0.198, 0.191
$Cu_{60}Zr_{40}$	0.071	0.16, 0.12, 0.14, 0.14, 0.14
$Ni_{81}B_{19}$	-2.664	-9.8802
$Be_{70}Al_{30}$	0.323	-0.140, 0.286, 0.286, 0.285
$Cd_{90}Ge_{10}$	0.293	0.1788
$Cu_{33}Y_{67}$	-1.258	-2.4412
$Cu_{55}Zr_{45}$	0.154	0.23, 0.2063, 0.2194, 0.2225, 0.2220
$Ca_{60}Al_{40}$	0.427	0.3922
$Cu_{50}Zr_{50}$	0.213	0.2712],0.25, 0.257, 0.26, 0.26
$La_{80}Au_{20}$	0.397	0.3505
$Cu_{45}Zr_{55}$	0.249	0.30, 0.28, 0.29, 0.28, 0.28
$Ni_{33}Y_{67}$	-1.006	-2.1115
$Ni_{31}Dy_{69}$	-2.246	-2.7015
$Cu_{43}Ti_{57}$	0.443	0.3933
$Cu_{40}Zr_{60}$	0.285	0.33, 0.31, 0.32, 0.32, 0.32
$Cu_{35}Zr_{65}$	0.303	0.35,0.34, 0.34, 0.34, 0.34
$Cu_{60}W_{40}$	0.448	0.4007
$Fe_{80}B_{20}$	0.462	0.4210
$Fe_{83}B_{17}$	0.392	0.2664
$La_{80}Ga_{20}$	0.388	0.3315
$Ni_{50}Zr_{50}$	0.383	0.2882
$Cu_{33}Zr_{67}$	0.309	0.35, 0.34, 0.35, 0.35, 0.35
$Cu_{57}Zr_{43}$	0.306	0.1662
$Cu_{30}Zr_{70}$	0.324	0.36, 0.35, 0.36, 0.36, 0.35
$Fe_{90}Zr_{10}$	0.440	0.379
$Ni_{60}Nb_{40}$	0.468	0.4392
$Pd_{80}Si_{20}$	0.475	0.4547
$Cu_{25}Zr_{75}$	0.338	0.37, 0.37, 0.37, 0.37, 0.37
$Ni_{36}Zr_{64}$	0.402	0.3236
$Tl_{90}Te_{10}$	0.452	0.4651,0.45, 0.46
$Co_{67}Zr_{33}$	0.468	0.4391
$Zr_{67}Ni_{33}$	0.386	0.2885
$Fe_{80}P_{20}$	0.347	0.1676
$In_{80}Sb_{20}$	0.445	0.4546
$Zr_{70}Be_{30}$	0.226	-0.087
$Zr_{70}Pd_{30}$	0.330	0.1958
$Zr_{70}Co_{30}$	0.365	–
$Pd_{35}Zr_{65}$	0.257	0.1146
$Pb_{90}Cu_{10}$	0.450	0.4216
$Sn_{90}Cu_{10}$	0.423	0.3747
$Zr_{75}Rh_{25}$	0.364	0.2479
$Pb_{75}Bi_{25}$	0.462	0.472, 0.47,0.47
$Pb_{50}Bi_{50}$	0.462	0.4715

The lower values of T_C for $Mg_{84}Ni_{16}$, $Cu_{33}Y_{67}$, $Ni_{33}Y_{67}$, $Ni_{81}B_{19}$ and $Ni_{31}Dy_{69}$ metallic glasses and higher values of T_C for $Pd_{80}Si_{20}$, $Cu_{66}Ti_{34}$, $Cu_{60}Zr_{40}$, $Cu_{60}W_{40}$, $Fe_{90}Zr_{10}$, $Ni_{60}Nb_{40}$, $Co_{67}Zr_{33}$, $Fe_{80}B_{20}$ and $Fe_{83}B_{17}$ metallic glasses may be due to the electron transfer between the transition metal and other metallic element.

Table 6. Effective interaction strength ($N_O V$) of binary metallic glasses.

Metallic glass	Present	Others [4-22]
$Au_{84}Si_{16}$	0.2661	0.2753
$Mg_{85.5}Cu_{14.5}$	0.2126	0.2175
$Ca_{70}Mg_{30}$	0.3694	0.37,0.37,0.45,0.52,0.52, 0.52, 0.61, 0.63, 0.66
$Ca_{70}Zn_{30}$	0.2442	0.2407
$Mg_{70}Zn_{30}$	0.2523	0.19,0.16,0.23,0.23, 0.29
$Mg_{84}Ni_{16}$	0.1200	0.1243
$Cu_{66}Ti_{34}$	0.4073	0.4238
$Be_{90}Al_{10}$	0.2673	0.29,0.286, 0.288, 0.285
$Cu_{60}Zr_{40}$	0.1970	0.20,0.189,0.1875, 0.18, 0.18
$Ni_{81}B_{19}$	0.0872	0.091
$Be_{70}Al_{30}$	0.3305	0.296, 0.287, 0.288, 0.287
$Cd_{90}Ge_{10}$	0.2717	0.284
$Cu_{33}Y_{67}$	0.1158	0.122
$Cu_{55}Zr_{45}$	0.2155	0.228, 0.21,0.209, 0.208, 0.205
$Ca_{60}Al_{40}$	0.5020	0.5129
$Cu_{50}Zr_{50}$	0.2329	0.241, 0.22,0.22, 0.220, 0.217
$La_{80}Au_{20}$	0.3723	0.3770
$Cu_{45}Zr_{55}$	0.2458	0.254, 0.24,0.23, 0.232, 0.229
$Ni_{33}Y_{67}$	0.1228	0.1309
$Ni_{31}Dy_{69}$	0.0909	0.1150
$Cu_{43}Ti_{57}$	0.4781	0.4978
$Cu_{40}Zr_{60}$	0.2622	0.27, 0.254,0.249, 0.248, 0.25
$Cu_{35}Zr_{65}$	0.2715	0.28, 0.267,0.262, 0.26, 0.26
$Cu_{60}W_{40}$	0.4639	0.4825
$Fe_{80}B_{20}$	0.5444	0.5715
$Fe_{83}B_{17}$	0.3515	0.3746
$La_{80}Ga_{20}$	0.3608	0.3676
$Ni_{50}Zr_{50}$	0.3459	0.3664
$Cu_{33}Zr_{67}$	0.2748	0.29,0.27, 0.265, 0.264, 0.26
$Cu_{57}Zr_{43}$	0.2869	0.2984
$Cu_{30}Zr_{70}$	0.2845	0.298, 0.28,0.275, 0.27, 0.270
$Fe_{90}Zr_{10}$	0.4524	0.4747
$Ni_{60}Nb_{40}$	0.5796	0.6071
$Pd_{80}Si_{20}$	0.6501	0.6773
$Cu_{25}Zr_{75}$	0.2937	0.307,0.289,0.28, 0.282, 0.279
$Ni_{36}Zr_{64}$	0.3759	0.3973
$Tl_{90}Te_{10}$	0.4566	0.6481, 0.39, 0.41
$Co_{67}Zr_{33}$	0.5889	0.6120
$Zr_{67}Ni_{33}$	0.3515	0.3673
$Fe_{80}P_{20}$	0.3025	0.3282
$In_{80}Sb_{20}$	0.4446	0.6123, 0.39, 0.46
$Zr_{70}Be_{30}$	0.2539	0.2657
$Zr_{70}Pd_{30}$	0.2827	0.2956
$Zr_{70}Co_{30}$	0.2887	–
$Pd_{35}Zr_{65}$	0.2705	0.2784
$Pb_{90}Cu_{10}$	0.4676	0.4785
$Sn_{90}Cu_{10}$	0.3994	0.4202
$Zr_{75}Rh_{25}$	0.3165	0.3311
$Pb_{75}Bi_{25}$	0.5127	0.739, 0.49, 0.55
$Pb_{50}Bi_{50}$	0.5086	0.7331

The increase in T_C has also been attributed to the excitonic mechanism resulting from the granular structure separated by semiconducting or insulating materials **[2]**. It is also seen that, T_C decreases almost linearly with increasing Cu-concentration (X). The value of T_C is found in the range, which is suitable for further exploring the applications of the metallic glasses for usage like lossless transmission line for cryogenic applications. While metallic 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 α for binary metallic glasses are tabulated in **Table 5.** The values of α show a weak dependence on the dielectric screening function. The negative value of α is observed in the case of some metallic glasses, which indicates that the electron-phonon coupling in these metallic complexes does not fully explain all the features regarding their superconducting behaviour. The comparisons of present results with other such theoretical data **[4-22]** are highly encouraging. Since the experimental value of α has not been reported in the literature so far, the present data of α may be used for the study of ionic vibrations in the superconductivity of amorphous substances. The most important feature noted here is that as the concentration (X) of Cu (in at %) increases the present results of α decreases.

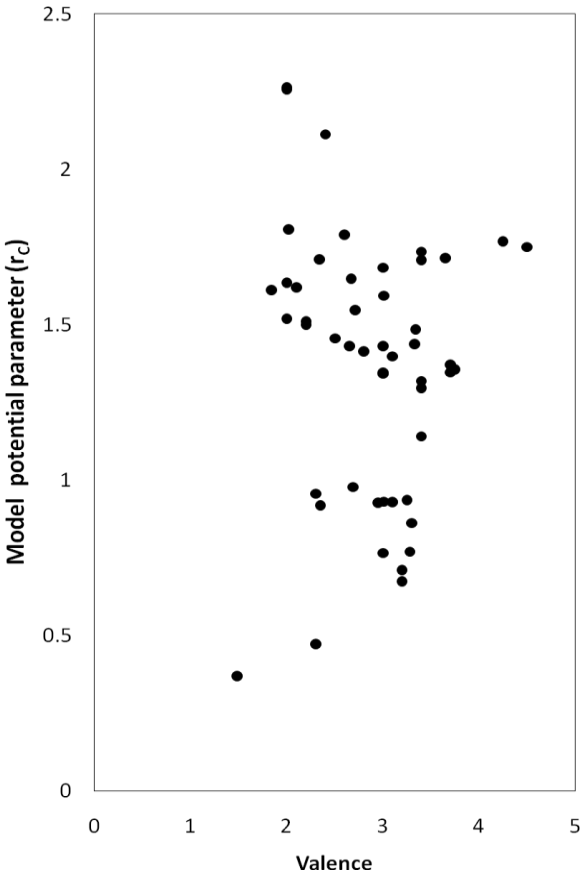

Fig. 1. Model potential parameter (r_C) Vs. valance (in at %).

The values of the effective interaction strength $N_O V$ are listed in **Table 6**. It is observed that the magnitude of $N_O V$ show that the metallic glasses under investigation lie in the range of weak coupling superconductors. The present results are found qualitative agreement with the available theoretical data **[4-22]**. The variation of present values of the $N_O V$ show that, the metallic glasses under consideration fall in the range of weak coupling superconductors. It is also observed that as

the concentration (X) of Cu (in at %) increases the present results of $N_O V$ decreases.

The graphical nature of the superconducting state parameters with concentration (in at %) of the second metallic component is displayed in **Fig. 3**. Also, presently computed transition temperature T_C of binary metallic glasses is shown in **Fig. 4**, while **Fig. 5** represented the variation of the transition temperature T_C with valance of binary metallic glasses. All the graphs suggested that, the reported binary metallic glasses are exhibiting superconducting nature in the present case.

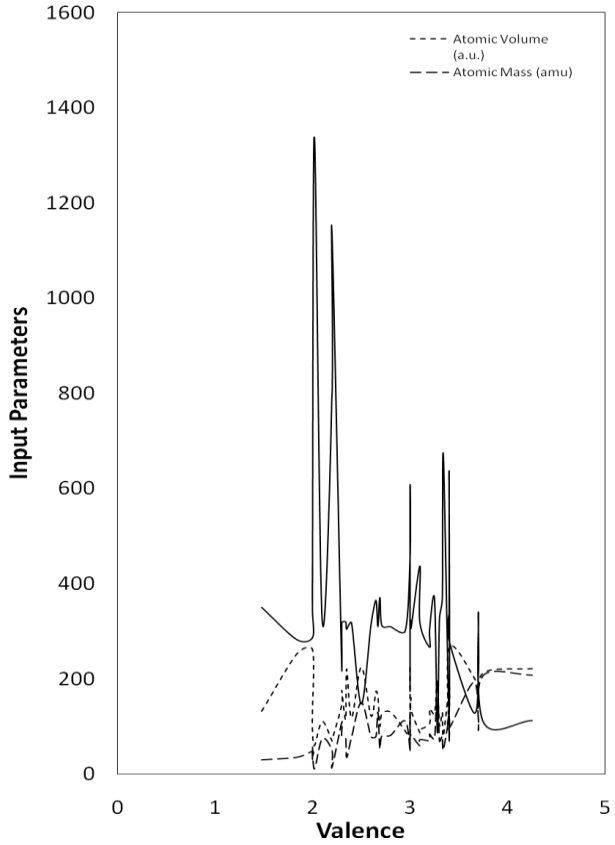

Fig. 2. Input parameters Vs valance (in at %).

It can be noted from the **Table 2-6** that, when we go from $Be_{90}Al_{10}$ → $Zr_{75}Rh_{25}$ metallic glasses of superconducting-superconducting (S-S) elements, the SSP increases except for $Zr_{70}Be_{30}$ and $Zr_{75}Rh_{25}$ metallic glasses the SSP decreases. While in the case of metallic glasses of superconducting-conditional superconducting (S-S') elements (i.e. $Ca_{70}Zn_{30}$ → $Pb_{50}Bi_{50}$), the SSP increases except the SSP for $Tl_{90}Te_{10}$, $In_{80}Sb_{20}$ and $Pb_{50}Bi_{50}$ decreases. In the case of metallic glasses of superconducting-non superconducting (S-NS) elements (i.e. $Au_{84}Si_{16}$ → $Fe_{80}P_{20}$), the SSP decreases except for $Ni_{33}Y_{67}$, $Pd_{80}Si_{20}$ and $Fe_{80}P_{20}$ metallic glasses the SSP increases. While in the case of metallic glass of conditional superconducting-conditional superconducting (S'-S') elements (i.e. $Ca_{70}Mg_{30}$), the present results of the SSP show an excellent agreement with the available data. Also, the metallic glasses of conditional superconducting-non superconducting (S'-NS) elements, when we go from $Cu_{66}Ti_{34}$→ $Sn_{90}Cu_{10}$, the SSP increases except the SSP for $Ni_{50}Zr_{50}$, Fe_{90} Zr_{10}, $Ni_{36}Zr_{64}$, $Zr_{67}Ni_{33}$, $Zr_{70}Pd_{30}$, $Pd_{35}Zr_{65}$ and $Sn_{90}Cu_{10}$ decreases. The SSP of metallic glasses of non-superconducting-non superconducting (NS-NS) elements (i.e. $Ni_{81}B_{19}$ → $Fe_{83}B_{17}$), the SSP increases except for $Fe_{83}B_{17}$ metallic glass the SSP decreases.

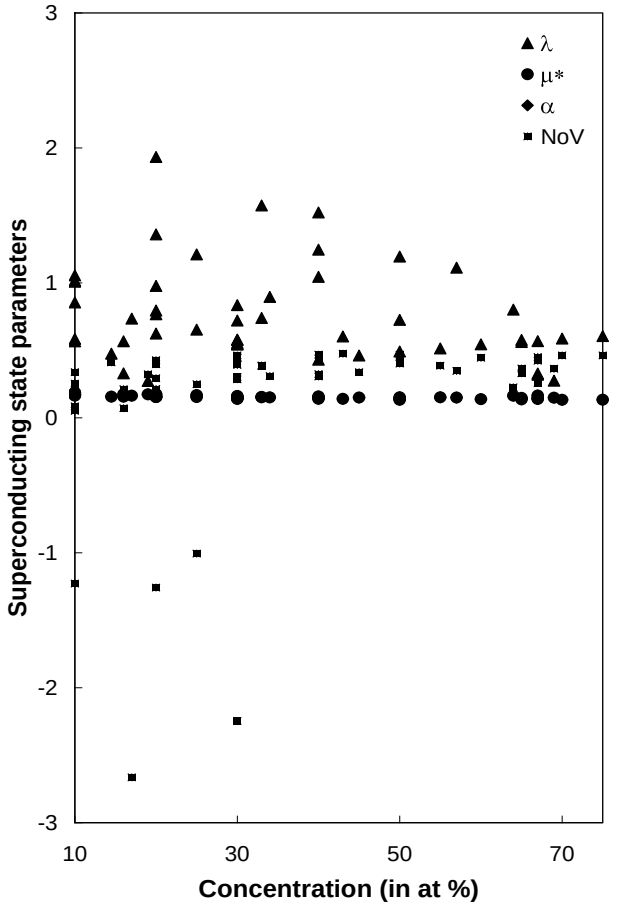

Fig. 3. Superconducting state parameters (SSP) Vs. concentration (in at %).

All the metallic glasses are based on superconducting (S) (Be, Al, Ti, Zn, Ga, Zr, Nb, Rh, Cd, In, Sn, W, Tl, Pb and La), conditional superconducting (S') (Mg, Si, P, Ca and Bi) and non-superconducting (NS) (B, Fe, Co, Ni, Cu, Ge, Y, Pd, Sb, Te, Au and Dy) elements of the periodic table. Most of the amorphous alloys exhibit the superconductivity phenomena under pressure or as thin film. But, in the present case, these theoretical computations show all the metallic glasses of different elements of the periodic table exhibit superconducting nature accurately. The nature of the parameters of the superconductivity is highly affected by the nature of the elements of the periodic table. This may be the reason that, the composing elements of the metallic glasses are played an important role in the nature of the SSP.

According to Matthias rules **[33, 34]**, binary metallic glasses having Z<2 do not exhibits superconducting nature. Hence, $Au_{84}Si_{16}$ and $Mg_{85.5}Cu_{14.5}$ metallic glasses are non-superconductors, but they exhibit superconducting nature in the present case. When we go from Z=2 to

Z=4.5, the electron-phonon coupling strength λ changes with lattice spacing "a". Similar trends are also observed in the values of T_C for all metallic glasses. Hence, a strong dependency of the SSP of the metallic glasses on the valence Z is found, which was shown in the **Fig. 5**.

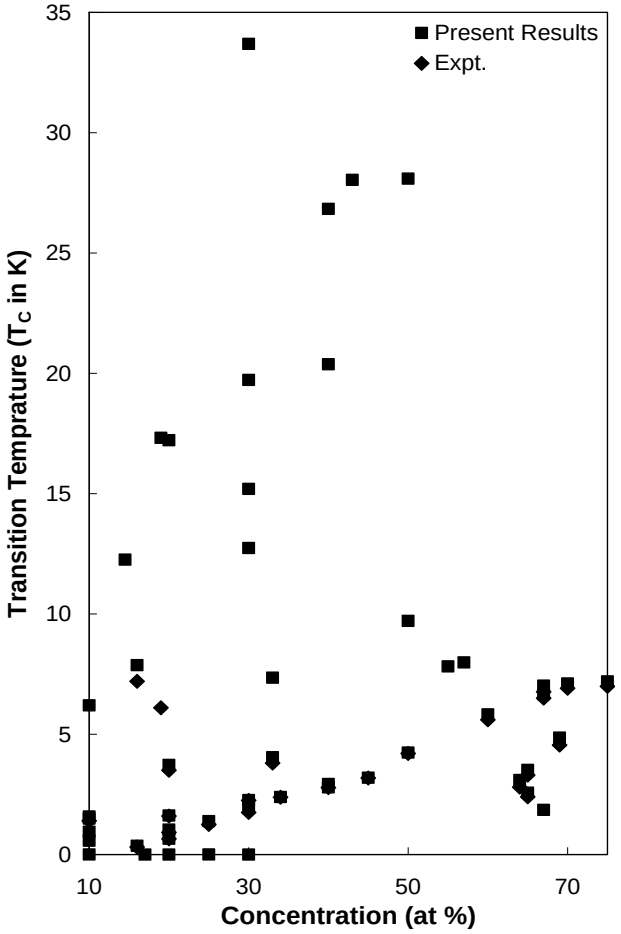

Fig. 4. Transition temperature (T_C in K) vs concentration (in at %).

For comparison of SSP, theoretical or experimental data for only forty nine metallic glasses are available in the literature. This comparisons show qualitative results and favours applicability of EMC model potential with PAA approach in studying the SSP of the binary metallic glasses. In contrast with the reported studies, the present study spans the metallic glasses based on the large number of the superconducting (S), conditional superconducting (S') and non-superconducting (NS) elements of the periodic table on a common platform of model potential. Hence, the present investigation provides an important set of data for these metallic glasses which can be very useful for further comparison either with theory or experiment.

Lastly, we would like to emphasize the importance of involving a precise form for the pseudopotential. It must be confessed that although the effect of pseudopotential 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 nonsuperconducting region. 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.

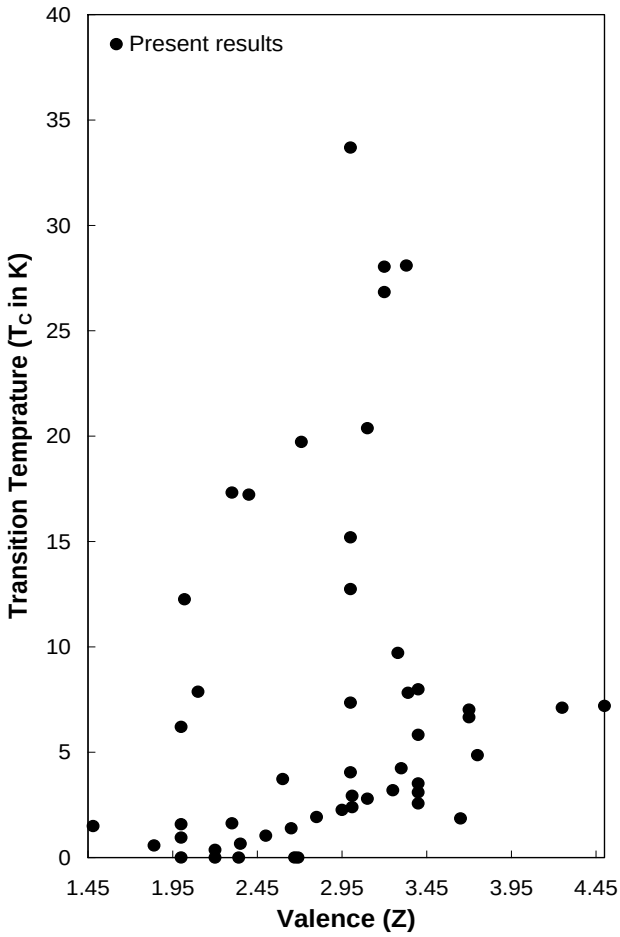

Fig. 5. Transition temperature (T_C in K) Vs. valance.

Conclusion

The comparison of presently computed results of the SSP of the metallic glasses based on the large number of superconducting (S), conditional superconducting (S') and non-superconducting (NS) elements of the periodic table with available theoretical and experimental findings are highly encouraging, which confirms the applicability of the EMC model potential and different forms of the local field correction functions. A strong dependency of the SSP of metallic glasses on the valence Z is found. The T_C obtained from F-local field correction function are found an excellent agreement with available theoretical or experimental data. The experimentally observed values of the SSP are not available for the most of the metallic glasses therefore it is difficult to drew any special remarks. However, the comparison with other such theoretical and experimental data supports the present approach of PAA. Such study on SSP of other multi component amorphous alloys is in progress.

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