## Abstract

The nano-micromechanical behaviour of the as-cast and cold rolled plates of $Zr_{41.2}Ti_{13.8}Cu_{12.5}Ni_{10}Be_{22.5}$ (VIT1), $Zr_{52.5}Cu_{18}Ni_{14.5}Al_{10}Ti_5$ (VIT105), $Zr_{58.5}Cu_{15.6}Ni_{12.8}Al_{10.3}$-$Nb_{2.8}$ (VIT106A) and $Zr_{55}Cu_{30}Ni_5Al_{10}$ (*at*. %) bulk metallic glasses (BMGs) with different glass fragility parameters in the range of 39-69, has been investigated using instrumented nanoindentation in constant loading rate (CLR) and constant strain rate (CSR) mode on the surfaces and inner core. The hardness (*H*), Young's modulus (*E*), indentation size effect (ISE), strain rate sensitivity (*m*) and activation volume ($V^*$) under CLR and CSR modes of surfaces and inner core of the as-cast samples identified as LW and TW planes, were studied. The effect of testing conditions on the deformation mechanism of BMGs and the observed strain rate sensitivity have been discussed in terms size and dynamics of shear transformation zones (STZs) by considering the presence of solid-liquid like regions in the glassy structure. The solid-liquid like regions in the glassy structure affects the deformation mechanism of BMGs as the liquid-like regions trigger the activation of the STZs, which promote formation of shear bands at various testing conditions. The as-cast plates of VIT1, VIT105 and VIT106A were cold rolled up to 30% strains. The effect of cold rolling on the *H* and E values of the rolling-width (RW), normal-rolling (NR), normal-width (NW) planes in VIT1, VIT105 and VIT106A has been investigated at peak loads in the range of 50 mN-500 mN. The 3D optical surface profilometry on cold rolled specimens revealed that the shear band width has reduced and shear band offset height has enhanced with the increase of cold rolling extent. Calorimetric studies and model calculations disclose that the free volume annihilation rate dominated over the free volume creation rate in hardened VIT1 cold rolled samples, which resulted in relaxed and dense glassy structure, exhibiting improved *H* and *E*. Cold rolling modifies the medium-range order glassy structure, which is responsible for the observed softening and hardening behavior. The cold rolling reduces the number and magnitude of pop-in events at a given loading rate resulting in continuum yielding and a gradual transition from inhomogeneous to homogeneous flow behavior with increasing cold rolling strain. The total discrete bursts ($h_{dis}/h_{plas}$) during plastic flow, deformation acceleration factor (*A*), and the number of the shear bands around and beneath the indentation impressions were reduced at a given loading rate with the increase of the cold rolling extent indicating a continuum yielding and a transition from inhomogeneous deformation (stair-step-like) to a homogeneous deformation leading to a smoother parabolic *P*-*h* curve upon cold rolling.



*Keywords:* Bulk metallic glasses, nanoindentation, cold rolling, hardness, strain rate sensitivity, activation volume, free volume, shear transformation zones.