Rejuvenation of Disorder-Containing Materials

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Abstract. Here, we report on experimental studies of metallic glass and nanocrystalline materials and novel synthesis and processing routes for controlling the structural state – and as a consequence, the mechanical properties. A particular focus will be on strategies for rejuvenation of disorder with the goal of suppressing shear localization and endowing damage tolerance. We also describe a microscopic structural quantity designed by machine learning to be maximally predictive of plastic rearrangements and further demonstrate a causal link between this measure and both the size of rearrangements and the macroscopic yield strain. We find remarkable commonality in all of these quantities in disordered materials with vastly different inter-particle interactions and spanning a large range of elastic modulus and particle size.

Keywords: Rejuvenation, disordered materials, nanocrystalline materials, softness.

1 Background

The nonequilibrium nature of kinetically frozen solids such as metallic glasses (MGs) is at once responsible for their unusual properties, complex and cooperative deformation mechanisms, and their ability to explore various metastable states in the rugged potential energy landscape. These features coupled with the presence of a glass transition temperature, above which the solid flows like a supercooled liquid, open the door to thermoplastic forming operations at low thermal budget as well as thermomechanical treatments that can either age (structurally relax) or rejuvenate the glass. Thus, glasses can exist in various structural states depending on their synthesis method and thermomechanical history. Nanocrystalline (NC) metals, also considered to be far-from-equilibrium materials owing to the large fraction of atoms residing near grain boundaries (GBs), share many commonalities with MGs both in terms of plastic deformation and its dependence on processing history. Despite these similarities, the disorder intrinsic to both classes of materials has precluded the development of structure-property relationships that can capture the multiplicity of energetic states that glasses and GBs may possess.

We describe and use a microscopic structural quantity designed by machine learning to be maximally predictive of plastic rearrangements and further demonstrate a causal link between this measure and both the size of rearrangements and the macroscopic yield strain [1]. We find remarkable commonality in all of these quantities in disordered materials with vastly different inter-particle interactions and spanning a large range of elastic modulus and particle size. We further explore the commonalities between disorder-containing NC and MG materials by using femtosecond laser processing as a unique non-equilibrium process that can generate complex stress states due to ultrafast electronic excitation and subsequent relaxation events. Experiments on NC Al-O and Cu-Zr alloys indicate that sub-ablation femtosecond laser pulses cause a dramatic reduction in hardness accompanied by negligible changes in grain size. Parallels between our results and rejuvenation processes in glassy systems will be discussed in the context of controlling metastable structural configurations through novel processing routes.

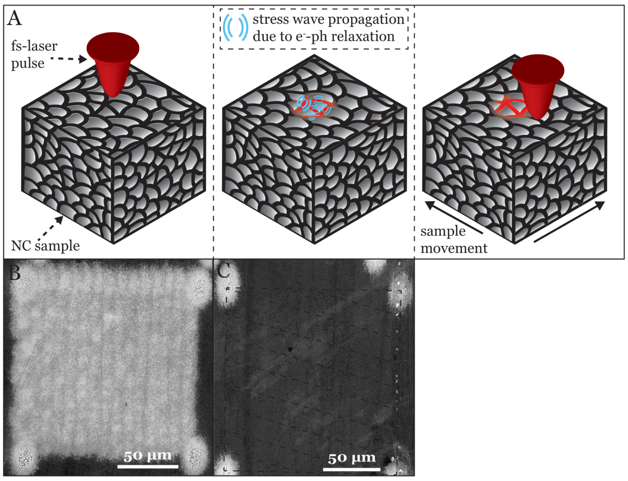

Fig. 1. A) Schematic showing the fs-laser treatment procedure. A single fs-pulse irradiates the NC sample, which then emits elastic waves. Once this process has completed, the sample is translated and irradiated with a series of pulses until the desired size is reached. B) SEM image of the Al-4.8 at%O sample irradiated with a fluence above the ablation threshold. The four lighter areas on the corners of the square are fiducial marks. C) SEM image of the Al-4.8 at%O sample irradiated with a fluence below the ablation threshold.

References

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