Materials scientists and engineers aim to design and develop bulk metallic glasses (BMGs) with excellent properties. The main technical challenge is to scale up their size and improve the material properties in the lab. Now writing on Science Advances, Jiang Ma and a team of interdisciplinary researchers addressed the problem by collaborating across the departments of Micro/Nano Optomechatronic Engineering, Mechanical Engineering, Computational Science Research and the Institutes of Mechanics and Physics. They demonstrated a new method to synthesize BMGs (bulk metallic glasses) and metallic glass-glass composites using metallic-glass ribbons. Using ultrasonic vibrations, they fully activated the atomic-scale stress relaxation within the ultrathin surface layer to accelerate atomic bonding between ribbons at a low temperature; far below the glass transition point. The new approach overcame the size and compositional limits associated with conventional methods to facilitate rapid bonding of metallic glasses of distinct physical properties without crystallization. The research work opens a new window to synthesize BMGs of extended composition to enable the discovery of multifunctional glass-glass composites that have hitherto remained unreported.

Glass is an indispensable material throughout human history, playing a practical role in scientific research and daily life. Natural or man-made variants of glass find extreme applications in optics, biotechnology, medicine and electronics. Bulk metallic glasses are a good model material for the study of the structure and properties of dense random packing glasses, attracting a great deal of attention since their discovery. The materials are very promising in future applications to develop sporting goods, biomedical devices and electronic devices due to their high elastic limit and excellent wear/radiation resistance.

However, the crystallization rates of the known glass-forming metallic liquids remain orders of magnitude higher than common glass-forming materials such as polymers, silicates or molecular liquids. As a result, the glass forming ability (GFA) remains a longstanding issue for fundamental research, while introducing a bottleneck for potential applications of BMGs. Superior GFA is only found in a limited number of systems at present to form lead (Pd), zirconium (Zr) and titanium (Ti)-based BMGs. Researchers have made substantial efforts in the past to understand and improve the GFA of BMGs to overcome existing limits by incorporating thermodynamics, spark plasma sintering, thermoplastic joining methods and more recently artificial intelligence-guided high-throughput component selection.
Researchers have discovered the surface mobility of amorphous materials (materials with no detectable crystal structure) to be much faster than in bulk by studying a variety of materials. Strong evidence also exists to extend fast surface dynamics from monoatomic layers to the nanometer scale to form amorphous materials. While preceding work suggests that fast surface atomic dynamics can join metallic glasses of different types, simply touching two metallic glass surfaces at low temperatures does not immediately facilitate metallic bond formation. In order to join metallic glasses by accelerating surface atomic mobility, one must apply pressure and raise the temperature. In the present work, Ma et al. dramatically accelerated the surface mobility to create ultrafast metallic bonding under ultrasonic vibrations at room temperature. They overcame the limit of glass forming ability (GFA) to synthesize BMGs (bulk metallic glasses) and form metallic glass composites (GGCs) that have not been reported thus far.

To further understand metallic glass surface activation, the researchers studied the surface mobility of a model zirconium (Zr)-based metallic glass film by mapping its viscoelastic loss tangent (dimensionless measurement of a material) using dynamic scanning probe microscopy (DSPM). Physically, the activation energy is related to the energy required to trigger local hopping between neighboring sub-basins on the potential energy landscape. To statistically analyze the activation energy distribution profiles at the surface of a metallic glass, the research team divided the sample model into different layers four Angstrom (Å) in thickness parallel to the surface. The actual surface layer exhibited extraordinarily low energies (approximating 0.05 eV) to behave in an exponentially decaying mode to suggest the activation energy in the bulk region was distinct from the surface.

To explore the activation energy at the metallic glass surface and at the bulk, the scientists applied molecular dynamics (MD) simulations combined with activation-relaxation technique nouveau (ARTn). Physically, the activation energy is related to the energy required to trigger local hopping between neighboring sub-basins on the potential energy landscape. To statistically analyze the activation energy distribution profiles at the surface
The mapping results strongly supported the view that surface atoms in metallic glasses maintained fast mobility. Ma et al. therefore expect a fast bonding process to be effectively activated in the presence of an appropriately high driving frequency.

To facilitate a high driving frequency-induced fast bonding process, the scientists conducted ultrasonic vibration on crumbled BMG ribbons. For this, they placed the metallic glass ribbon samples in a base plate with a cavity made of cemented carbide and applied a low preload pressure (~ 12 MPa) to clamp the ribbons tightly. They then applied the sonotrode (an acoustic drill) at a frequency of 20,000 Hz. The team used three different typical alloy systems including lanthanum (La)-based, lead (Pb)-based, and zirconium (Zr)-based metallic glass ribbon samples, previously prepared using conventional melt-spun processes.

Inspired by the initial results, Ma et al. engineered BMGs with multiple amorphous phases and components using high-frequency vibrations and in broken litters. Notably, the unique amorphous nature was key to ribbon joining to form BMGs as non-crystalline samples that remained amorphous during high-frequency ultrasonic vibration. The ultrasonically fabricated BMGs were dense as as-cast samples and demonstrated low porosities. The preliminary results of the new approach are promising to develop metallic glasses of a bulk size.

created multiphased BMGs combining different types of ribbons. To accomplish this, they cut metallic glass ribbons of different systems into pieces, mixed them in a mold cavity and obtained bulk samples using ultrasonic vibrations to join the ribbons together in a bulk.

The research team used X-ray diffraction patterns to demonstrate that both single and multiphased BMGs retained their amorphous structures. The scientists also investigated the micro-scale and atomic structures of BMGs using high-resolution transmission electron microscopy (HRTEM) to confirm the presence of distinct amorphous structures of different phases. To study the elemental distribution across the interface, they used energy-dispersive spectroscopy (EDS) and noted a level of intermixing through diffusion. Thereafter, using molecular dynamics (MD) simulations, Ma et al. revealed the atomic origin of ultrasound-enabled fast bonding and noted the mobility of surface atoms to drastically differ from that in the bulk; which is typical for amorphous materials.

In this way, Jiang Ma and colleagues demonstrated an ultrasound-enabled joining approach to synthesize bulk-sized metallic glasses by using single or multiple amorphous phases. The process related fundamentally to the ultrafast mobility of metallic glasses. The new method allows the design of multiple phases and microstructures. The research outcomes will establish a new and flexible process to design and engineer novel metallic glass systems, to greatly extend the applications of amorphous materials.


