Extremely strong and yet incredibly ductile multicomponent alloys developed

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The new alloy Al_7Ti_7 exhibits a superior strength of 1.5 gigapascals and ductility as high as 50 percent in tension at ambient temperature. Credit: City University of Hong Kong

A research team led by City University of Hong Kong (CityU) has developed a strategy for creating new high-strength alloys that are extremely strong, ductile and flexible. The strategy overcomes the critical issues of the strength-ductility trade-off dilemma, paving the way for innovative structural materials in future.

Multiple-principal element alloys, generally referred as high-entropy alloys (HEAs), are a new type of material constructed with equal or nearly equal quantities of five or more metals. They are currently the focus of attention in materials science and engineering due to their potential structural applications. Yet most of the alloys share the same detrimental feature: The higher the strength of the alloy, the less the ductility and toughness, meaning that strong alloys tend to be less deformable or stretchable without fracture.

Recently, however, a study led by Professor Liu Chain Tsuan, University Distinguished Professor of the Department of Materials Science and Engineering at CityU, has found a breakthrough solution to this daunting decades-long dilemma— making high-entropy alloys through massive precipitation of nanoscale particles. This cutting-edge research has just been published in the latest issue of the prestigious journal *Science*, titled "Multicomponent intermetallic nanoparticles and superb mechanical behaviours of complex alloys."

Solving the strength-ductility trade-off

"We are able to make a new high-entropy alloy called Al_7Ti_7 ($(FeCoNi)_{86}$-Al_7Ti_7) with a superior strength of 1.5 gigapascals and ductility as high as 50 percent in tension at ambient temperature. Strengthened by nanoparticles, this new alloy is five times stronger than that of the iron-cobalt-nickel (FeCoNi)-based alloy," says Professor Liu.

"Most conventional alloys contain one or two major elements, such as nickel and iron to manufacture," he explains. "However, by adding additional elements of aluminum and titanium to form massive precipitates in the FeCoNi-based alloy, we have found both the strength and ductility have significantly increased, solving the critical issue of the trade-off dilemma for structural materials."

Moreover, high-strength alloys usually face plastic deformation instability, known as the necking problem, meaning that when the alloy is under a high strength, its deformation would become unstable and very easily lead to necking fracture (localized deformation) with very limited uniform elongation. But the team has further found that by adding multicomponent intermetallic nanoparticles, which are complex nanoparticles made of different elements, it can uniformly strengthen the alloy by improving the deformation instability.

Tackling the "necking problem"

And they have found the ideal formula for these complex nanoparticles, which consists of nickel, cobalt, iron, titanium and aluminium atoms. Professor Liu explains that each nanoparticle measures 30 to 50 nanometres. The iron and cobalt atoms that replace some of the nickel components help to reduce the valence electron density and improve the new alloy's ductility. On the other hand, replacing some of the aluminium with titanium largely reduces the impact of moisture in the air to avoid induced embrittlement in this new strong alloy.

"This research opens up a new design strategy to develop superalloys, by engineering multicomponent nanoparticles to strengthen complex alloys to achieve superb mechanical properties at room and elevated temperatures," says Professor Liu.

He believes that the new alloys developed with this novel strategy will perform well in temperatures ranging from -200°C to 1000°C. Hence they can act as a good base to further develop for structural use in cryogenic devices, aircraft and aeronautic systems and beyond.

More information: T. Yang et al, Multicomponent intermetallic nanoparticles and superb mechanical behaviors of complex alloys, *Science* (2018). DOI: 10.1126/science.aas8815

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