Properties of Selected High-strength Composite Conductors with Deformable and Non-deformable Strengthening Components (Thu-Mo-Po4.01-07)

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Abstract

High field magnets require the development and fabrication of large quantities of conductors with both high strength and high electrical conductivity. This combination of properties can be obtained from copper matrix composites either in macroscopic or microscopic form. Deformation can strengthen these composites further by either inducing dislocations or refining microstructure. During deformation, the strengthening component either retains its original shape or flows with the matrix, depending on its original hardness. In general, a non-deformable component is initially harder than one that deforms with the matrix. Co-deformation in both component and matrix leads to very high strength levels that are significantly greater than those that can be achieved in composites strengthened by non-deformable components. Thus, to properly choose a system for application in high field magnets, we must consider the detailed strengthening mechanisms that are operative in materials with ultra-fine scale microstructure. In this paper, we compare composites strengthened by either deformable or non-deformable components and describe parameters for the design and fabrication of materials selected for high field magnets.

Introduction

High field magnets require high-strength and high electrical conductivity coils. The coil requires the conducting wire, a reinforcement system, and an insulating material. In the current poster, consideration is given only to the development of the conductors required for high field magnets. The major portion of the poster will be devoted to comparison of high-strength composite conductors. In those conductors, the co-deformation behavior of matrix and the strengthening component will be discussed.

High-strength conductors can be manufactured from ceramic particle strengthened composites, where strengthening component won't be deformed with the Cu matrix. These conductors can also be made from the deformation of a variety of in situ composites. The essential relations to be established are between the design needs of the magnet system, the structure and properties of the conductor, and the methods of fabrication required to produce conductor systems of the required dimensions.

The strength levels required in the high strength conductors are of the order of 0.5 to 1.5 GPa, which is 1/3 of the shear modulus for copper. Hence the materials have strength levels within a factor of 2 or 3 of the theoretical strength because of the extremely fine structures developed by wire drawing. This poster discusses some features which determine both the strength and conductivity in these materials together with a brief discussion of future areas of fruitful research.

Composite Conductors before Cold Work

The fabrication of conductors starts, in most cases, with one of three processes: solidification, consolidation, or sintering. In solidified composites, the strengthening component is usually created during both solidification and subsequent heat treatment. In consolidated composites, the strengthening component usually maintains its predesigned size and shape. Different fabrication methods lead to different distribution patterns, density levels, and particle shapes, each influencing strength levels to a greater or lesser degree.

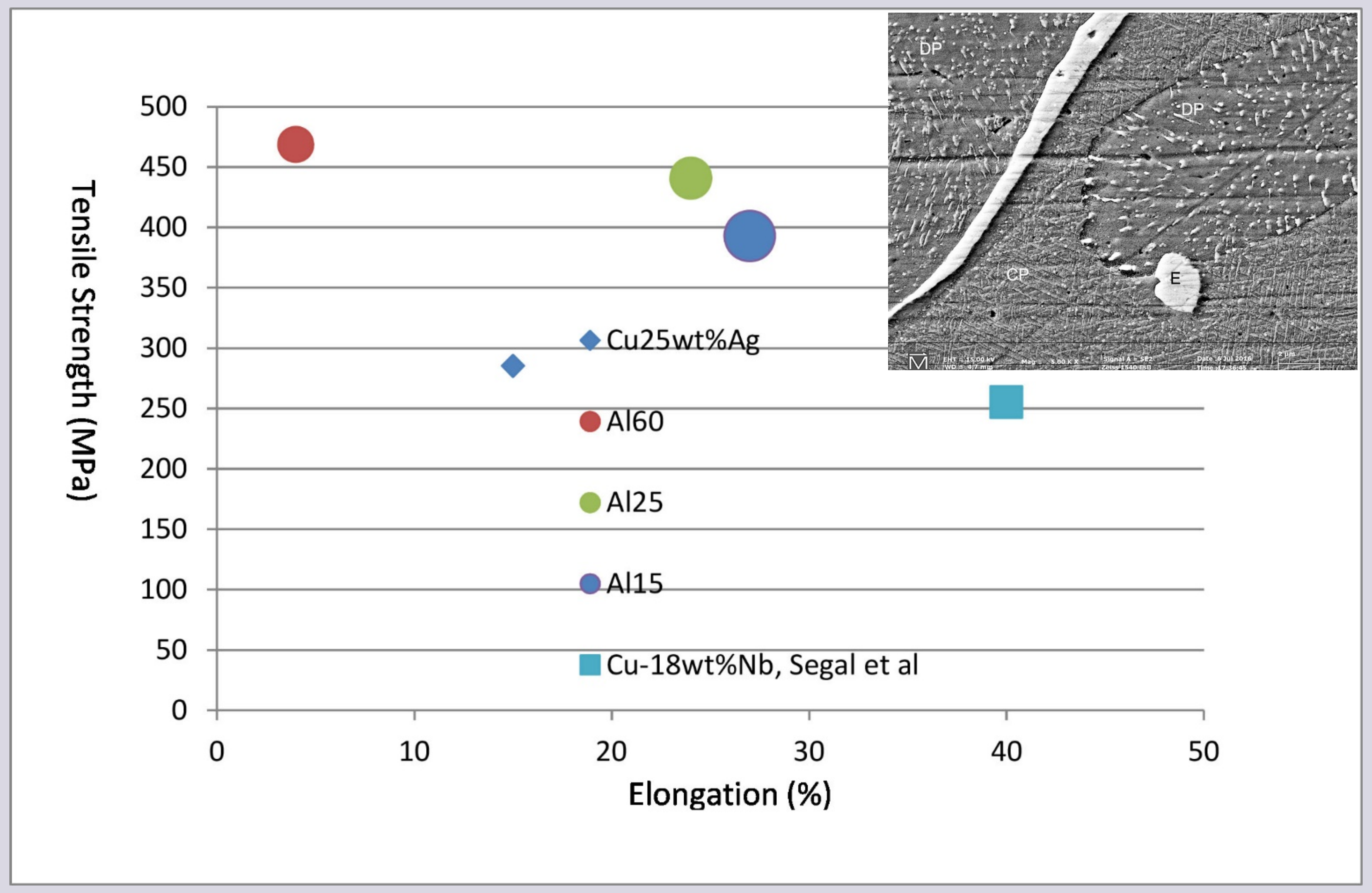

Figure 1. Comparison of ultimate tensile strength levels of composite conductors with deformable strengthening component and un-deformable strengthening component. Al15, Al25 and Al60 are conductors with alumina un-deformable particles and denoted by large round solid circles. Their work-hardening rates are relatively low. Cu-Ag is strengthened by deformable fibers and denoted by small solid diamond, indicating that relatively small ingot is required in order to achieve high strength. Cu-Nb is strengthened by deformable ribbons and denoted by medium sized solid squire, indicating medium sized ingot is needed to achieve high strength. (Cu-Nb data is from Segal et al, Al15, Al25 and Al60 data are from Höganäs AB)
Figure inset. Scanning electron microscopy image showing eutectic component (indicated by E) and proeutectic component. Both continuous precipitates (denoted by CP) and discontinuous precipitates (denoted by DP) occur in proeutectic component. The spacing between DP is about a few micrometers. The microbar is 2 μm in the image.

In our laboratory, one of the precursors used is GlidCop, which is a group of copper-matrix conductors (Al15, Al25 and Al60) strengthened by alumina particles. These conductors have relatively high strength in as-consolidated conditions. These strength levels are much higher than can be achieved in most other Cu matrix conductors that have not subjected to cold work.

Because of the coarse microstructure of Cu-Nb in as-cast condition, Cu-Nb composite ingots usually have lower mechanical strength than Cu-alumina billets. Cu-Nb composite, however, has much higher ductility and work-hardening rate. Therefore, if large deformation strain is used, it can achieve significantly higher mechanical strength than Cu-alumina.

Because of the coarse microstructure of Cu-Ag in as-cast condition, Cu-Ag ingots also have lower mechanical strength than Cu-alumina billets. In this case, however, Ag particles can sometimes precipitate out from the supersaturated solid solution formed during casting, giving Cu-Ag ingots higher mechanical strength than Cu-Nb ingots.

Composite Conductors after Cold Work

In US MagLab, most pulsed magnet would not have been possible without development of high strength conductors. Not only high strength and high conductivity, conductors with appropriate sizes are also required. Cu alloys with trace amount of alloying elements <0.5wt% (denoted as Cu(Ag) in this poster) are commercially available and can be made into long length and large cross-section wires. Because of low alloy content, the strain hardening rate was usually low. Therefore, the maximum achievable strength for this material was usually below 0.5 GPa.

In Cu-Ag composite with Ag content higher than 5wt%, strength greater than 900 MPa was achievable. This type of composite, however, is not commercially available.

GlidCop reached higher mechanical strength than Cu(Ag). The billets are commercially available. For composite with cross-section close to 100 mm^2, our results indicate the material can reach mechanical strength greater than 0.47 GPa after cold deformation. At this stress level, the average ratio of UTS over YS is below 1.06, indicating the composite have little room for further work hardening.

After cold-deformation, Cu-Nb can achieve very high strength. Our test of this material with cross-section~17 mm^2 demonstrated strength higher than 1 GPa.

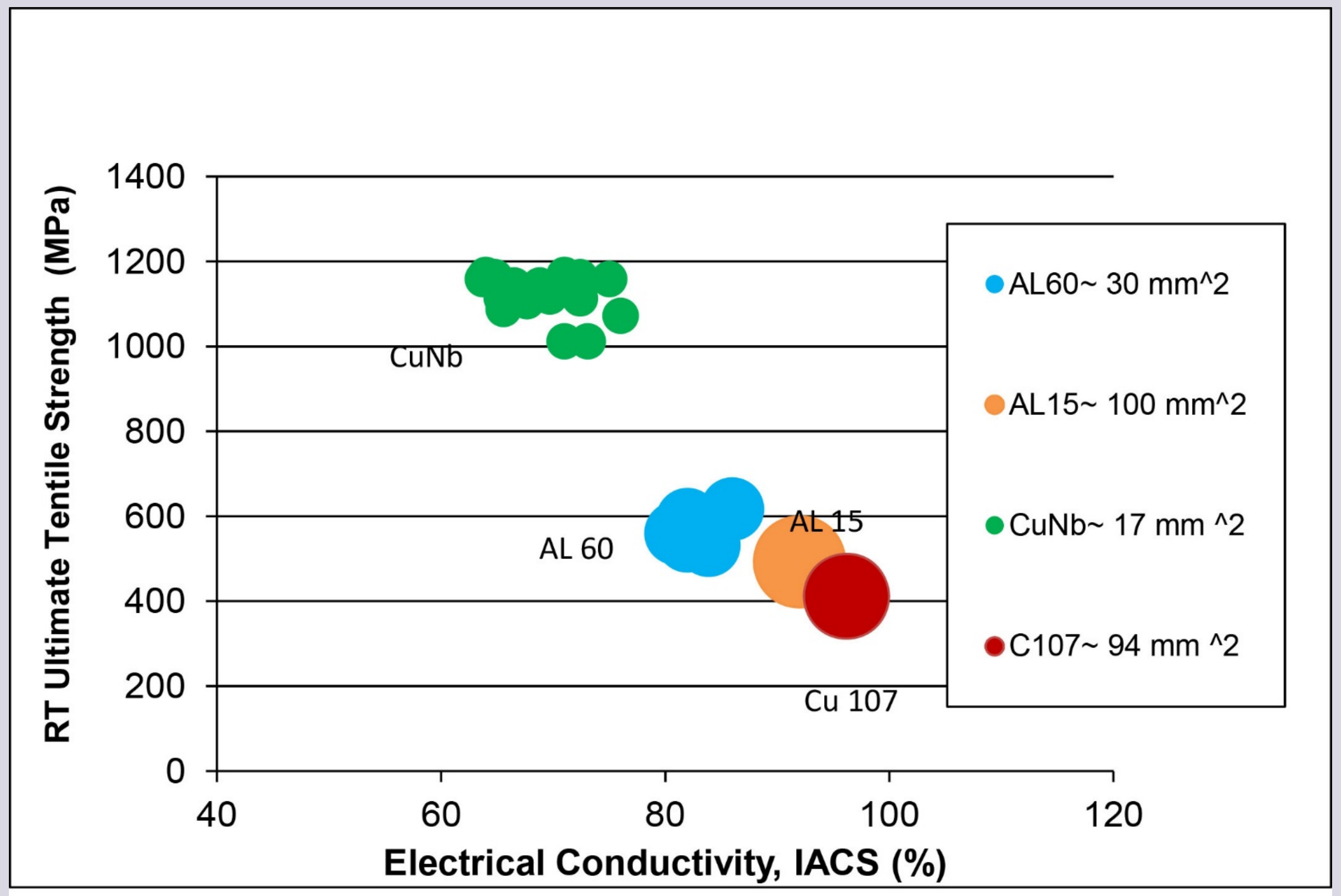

Figure 2 Comparison of room temperature (RT) tensile strength (MPa) and RT conductivity 100%IACS (International Annealed Copper Stand-ard, 100%IACS is equivalent to 1.724 μΩcm) of selected conductors in wire form; Al15, and Al60 are conductors with alumina un-deformable particles and denoted by large round solid circles, C107 is Cu+0.085wt%Ag and is denoted by a large circle. Cu-Nb is strengthened by deformable ribbons and denoted by small size circle, indicating small cross-section conductors. All composite conductors are in cold deformed condition.

Acknowledgments

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