Hydrogen embrittlement resistance of a high-strength copper-based alloy, CDA-C17200

Y. Ogawa[1] , J. Yamabe[2] H. Matsunaga[1] and S. Matsuoka[1]
[1]*Department of Mechanical Engineering, Kyushu University, Japan*
[2]*Department of Mechanical Engineering, Fukuoka University, Japan*
e-mail: yuhei.ogawa.bz@gmail.com

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In hydrogen refueling stations for fuel-cell vehicles (FCV) with 70 MPa hydrogen gas storage, hydrogen is refueled after having been cooled to approximately −40˚C to avoid temperature elevation inside of the FCV hydrogen tank. When attempting to develop a high-performance hydrogen pre-cooling system, three key properties should be considered for material selection: strength, thermal conductivity and resistance to hydrogen embrittlement (HE). At present, the components for high-pressure hydrogen applications are composed primarily of austenitic stainless steels due to their superior resistance to HE; however, the major drawback of these materials is their low-strength, *i.e.* 500~600 MPa in tensile strength, and low thermal conductivity. Thus, in order to develop safer and energy-efficient hydrogen pre-cooling system, a high-strength material with high thermal conductivity and excellent resistance to HE must be identified.

The present study therefore focuses on the precipitation-hardened, beryllium-copper alloy, CDA-C17200 as a serious candidate material. This alloy contains 1.8 wt. % Be and 0.25 wt. % Co in copper, and is generally strengthened by optimized aging heat treatment (2~3 hours at 315˚C) for precipitating nano-sized CuBe compounds in matrix phase. At the peak aged condition, the tensile strength of the material far exceeds 1000 MPa, and its thermal conductivity is more than tenfold of that found in austenitic stainless steels. In addition to such an outstanding material performance, it is well know that the hydrogen solubility in copper matrix is significantly low as compared with other structural metals such as iron, aluminum or nickel. Consequently, it is expected that the material also shows excellent resistance to HE.

In this study, we conducted slow-strain rate tensile (SSRT) tests in a 115 MPa gaseous hydrogen environment in order to assess the hydrogen compatibility of alloy CDA-C17200. Two types of the materials were prepared, so called CuBe-AT and -HT materials. The former was peak-aged immediately after solution annealing treatment (780˚C for 2 hours), conversely, the latter was subjected to 30% drawing process prior to aging heat treatment. In CuBe-HT, further strengthening of the mateirial is achieved due to the grain refinement and introduction of high density of dislocations. The tensile specimens of CuBe-AT and -HT were round-bar shaped with the diameter measuring 4 and 6 mm respectively, and the gauge length was 30 mm. The influence of hydrogen on the mecahinical performance was evaluated based on the relative reduction in area (RRA) value, which is the reduction in area in hydrogen gas devided by that with the absence of hydrogen.

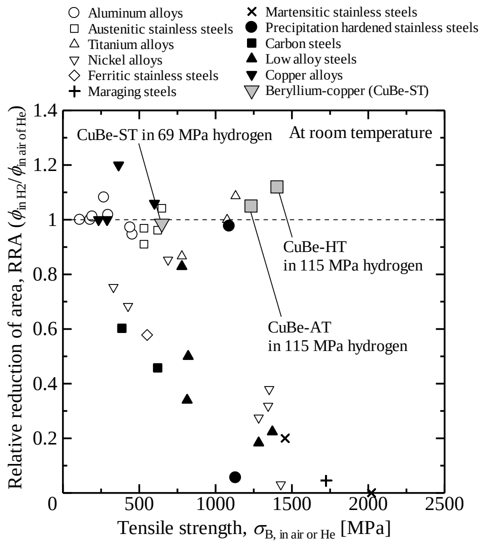

Fig. 1 Relationship between RRA and tensile strength of various materials in 69 MPa H_2 gas.

NASA conducted a comprehensive study on the hydrogen compatibility of various metallic materials including Fe-, Al-, Ni-, Ti- and Cu-based alloys by measuring tensile ductility loss in 69 MPa gaseous hydrogen [1]. In Fig. 1, we plotted the data of NASA' s study, together with the data of CuBe-AT and -HT obtained in the present study in 115 MPa hydrogen gas. In this diagram, the data of beryllium-copper alloy without precipitation-hardening treatment (CuBe-ST), which was obtained by NASA, is also included. As the general trend, there is a trade-off relationship between the RRA values and strength level of the material, and the tensile ductility loss becomes extreme in the materials with the tensile strength of more than 1200 MPa. However, note that both of CuBe-AT and -HT showed no hydrogen-induced ductility loss even though their tensile strength values exceeded 1200 MPa, showing the outstanding hydrogen embrittlement resistance as compared with other materials with the equivalent strength level. Our further study revealed that this material also showed no hydrogen-induced degradation even in other types of machanical testings, *e.g.* fatigue or fracture toughness tests [2]. Thus it can be concluded that precipitation-hardened beryllium-copper alloy has a large potential to be applied for heat exchangers which are exposed to high-pressure hydrogen gas.

[1] NASA, Safety Standard for Hydrogen and Hydrogen Systems, *NSS1740. 16*, 1997.

[2] Y. Ogawa, J. Yamabe, H. Matsunaga, S. Matsuoka, Material performance of age-hardened beryllium-copper alloy, CDA-C17200, in a high-pressure, gaseous hydrogen environment, *International Journal of hydrogen energy*, 42-26, 2017.