On the best compromise between strength, ductility and fracture toughness in metallic alloys

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The race for ultra-high strength in metallic alloys has turned into an even more complex quest for high strength/high ductility balance over the last two decades. Depending on the list of requirements of the applications, a minimum ductility is always needed at least for formability. More recently, it has been recognized that a high strength / high ductility compromise does not necessarily translate into high fracture toughness, involving the remnant confusion between the concepts of toughness and fracture toughness. A vast number of structural applications calls for an optimum trade-off between fracture toughness, strength and ductility with a weight that depends on the type of loading conditions and constraints. This has brought back to the front scene the old question of the link between fracture toughness and the two other properties.

In the simplest paradigm, fracture resistance expressed in terms of critical J integral J_{Ic} or critical energy release rate G_{Ic} is a product of strength, true fracture strain under the appropriate triaxiality and a microstructure length scale. The last aspect is often neglected as well as other contributors, such as a possible change of failure mechanism at crack tip compared to tensile bars, the resistance to void nucleation, the strain hardening capacity and the thickness dependent dissipation by crack tip necking in plates and sheets. Recent results on DP steels with elongated martensite second phases [1], Cantor type high entropy alloy, Ti-12wt.% Mo alloy [2], friction stir modified Al alloys [3] and stainless steel, will highlight several important messages on how to raise or to keep high fracture toughness in strong and ductile systems. A particularly revealing approach to quantify fracture resistance of high toughness system is the essential work of fracture. The analysis will also heavily rely on arguments from micromechanics-based models of nucleation, growth and coalescence of voids.

Keywords: fracture toughness, strength, ductility, metallic alloys

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