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LETTER TO THE EDITOR

Strength-ductility synergy: an incorrectly used term in materials science

*Jenő Gubicza**

Department of Materials Physics, Faculty of Science, Eötvös Loránd University, Pázmány P. sétány 1/A, H-1117 Budapest, Hungary

*Corresponding author: Tel: + 36-1-372-2876, Fax: +36-1-372-2811, e-mail: jeno.gubicza@ttk.elte.hu

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One of the hottest research topics in the field of plasticity of materials is the investigation of ways to achieve a combination of high mechanical strength and good ductility in metallic materials. Here, the strength can be either the yield strength or the ultimate tensile strength, and the ductility is characterized by either the maximum elongation at the end of the homogeneous deformation regime or the elongation to failure. Typically, the strength and ductility behave inversely, i.e., strong materials are brittle, while highly ductile materials tend to have lower strength. Overcoming this apparent incompatibility is a great task in materials science.

It was shown in the last decade that an appropriate selection of the chemical composition and the processing conditions of alloys could yield microstructures exhibiting improved or even exceptional combinations of high strength and good ductility [1-3]. Recently, Chen et al. [1] achieved an outstanding combination of strength and ductility for a Ti-rich alloy using cold rolling and subsequent annealing. However, these achievements are often termed misleadingly in related scientific publications. Namely, the obtained property combination is presented as "strength-ductility synergy" [4,5]. This is an imprecise and wrong application of the term "synergy". In its strictest sense, synergy implies that the combined effect of two or more factors exceeds the sum of their individual effects. For instance, a synergistic effect if the cooperative work of two employees is more powerful than the sum of the workpowers of the two persons operating separately. Thus, if we talk about strength-ductility synergy, there must be a third property which is influenced by both strength and ductility and for which the combined effect of strength and ductility is higher than the sum of the individual effects of these two quantities. This synergy effect can be presented in the following formula:

$$\Delta P(\Delta\sigma, \Delta\varepsilon = 0) + \Delta P(\Delta\sigma = 0, \Delta\varepsilon) < \Delta P(\Delta\sigma, \Delta\varepsilon) \quad (1)$$

where $\Delta\sigma$ and $\Delta\varepsilon$ are the changes in strength and ductility, respectively, while ΔP denotes the improvement of the third property influenced by both $\Delta\sigma$ and $\Delta\varepsilon$. However, in the article of Chen et al. [1] and almost all other papers in this field, the simultaneous improvement of both strength and ductility is termed "strength-ductility synergy," which is misleading. A mere co-existence of these properties does not constitute a synergy between them.

Fig. 1 shows the number of articles using “strength-ductility synergy” in their titles and published by March 17, 2025 (based on Web of Science) versus their publication year. Their total number is 522, but additional papers may also use this term wrongly in their body text only and not in the title. Most of these articles were published in the leading materials science journals, as shown in **Table 1**. Moreover, the number of these papers has increased steeply, as shown in **Fig. 1**. Therefore, it is very timely to stop this trend and start using a more suitable term. For instance, if a material exhibits both high strength and good ductility without the above-mentioned synergistic effect, it is suggested to use "exceptional strength-ductility combination", "improved strength-ductility balance", or "coexistence of high strength and good ductility".

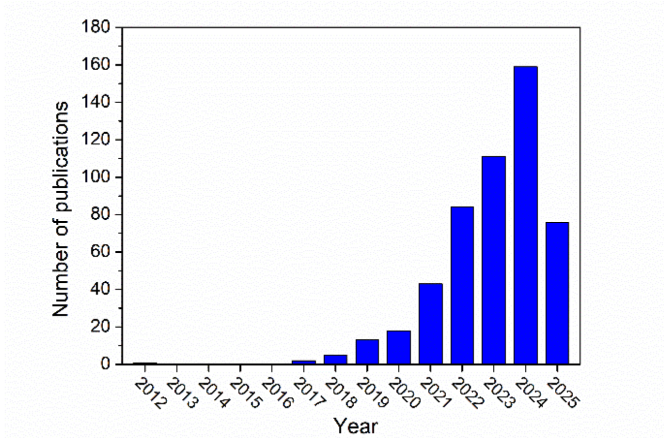

Fig. 1 Number of articles using the term “strength-ductility synergy” in their titles (published by March 17, 2025). Source: Web of Science (Clarivate).

Table 1 The top twenty journals published the largest number of articles using the term “strength-ductility synergy” in their titles (published by March 17, 2025).

Journal name	Number of publications
MATERIALS SCIENCE AND ENGINEERING A	122
JOURNAL OF ALLOYS AND COMPOUNDS	44
JOURNAL OF MATERIALS RESEARCH AND TECHNOLOGY	40
JOURNAL OF MATERIALS SCIENCE TECHNOLOGY	31
SCRIPTA MATERIALIA	26
INTERNATIONAL JOURNAL OF PLASTICITY	23
MATERIALS CHARACTERIZATION	17
MATERIALS LETTERS	16
MATERIALS DESIGN	15
ADDITIVE MANUFACTURING	14
COMPOSITES PART B ENGINEERING	13
MATERIALS RESEARCH LETTERS	11
ACTA MATERIALIA	10
JOURNAL OF MAGNESIUM AND ALLOYS	9
MATERIALS TODAY COMMUNICATIONS	8
COMPOSITES PART A APPLIED SCIENCE AND MANUFACTURING	7
JOURNAL OF MATERIALS SCIENCE	7
MATERIALS	7
ADVANCED ENGINEERING MATERIALS	5
INTERMETALLICS	5

It should also be noted that we can speak about synergy even in the case of the simultaneous improvement of strength and ductility. For example, suppose different mechanisms like twinning and formation of heterogeneous microstructure contribute simultaneously to an improved strength-ductility combination in a way that goes beyond the expected sum of their contributions. In that case, there is a synergy between these mechanisms. However, using the term "strength-ductility synergy" would be wrong in this case, too. In summary, while "strength-ductility synergy" is commonly used, its meaning is often ambiguous or overstated. It would benefit researchers to define more clearly whether they refer to a true synergistic effect or simply a favourable combination of both properties. In the latter case, "improved strength-ductility balance" is suggested. Still, the terms "exceptional strength-ductility combination" or "coexistence of high strength and good ductility" can be accepted.

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