metals

Editorial

Superplasticity and Superplastic Forming

Donato Sorgente

School of Engineering, University of Basilicata, Via Ateneo Lucano, 10, 85100 Potenza, Italy; donato.sorgente@unibas.it

1. Introduction and Scope

In both academic and industrial research endeavours, driving forces are essential to keep the interest alive for a specific topic. No matter how the social and technological scenarios evolve, curiosity and passion for a research topic are among the most effective spurs necessary to push the knowledge on physical phenomena involved in engineering problems into the unknown. This passion often paves the way for scientific discoveries and for industrial applications related to a specific phenomenon. Superplasticity is not an exception to this rule.

Superplasticity is a well-known phenomenon that has been observed on several metallic and non-metallic materials. Few decades after its first discovery, it has become undoubtedly the base principle for manufacturing complicated and highly integrated structures in aircrafts. Looking at Scopus-indexed documents containing the keywords "superplastic" or "superplasticity" over the past years, it is clear that, since the first publications appeared in the late 1960s, there has been a growing interest on this topic with the maximum being reached in the 2000s, with about 500 published documents per year (Figure 1). After a significant drop in the following 10 years, a plateau of a still remarkable figure of approximately 250 documents per year has been currently reached. Spikes in the curve are mostly concomitant with proceedings related to the International Conference on Superplasticity in Advanced Materials (ICSAM), which takes place every 3 years since 1982 and attracts around 100 to 150 researchers from all over the world.

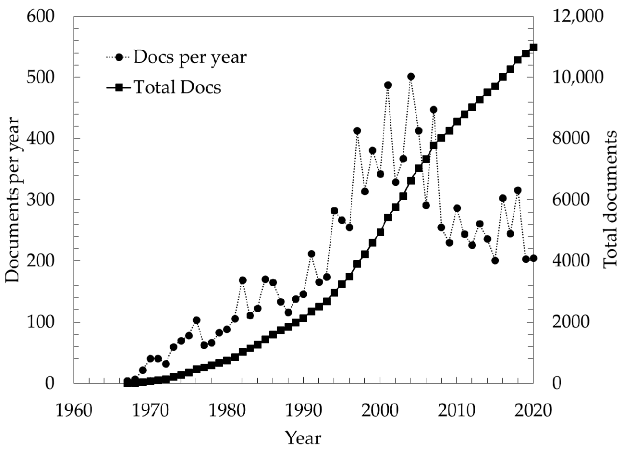

Figure 1. Scopus-indexed documents per year containing the keyword "superplastic" or "superplasticity".

So far, superplastic forming has become a well-established technology, especially in the aerospace sector and the deformation mechanisms behind this extraordinary behaviour have been largely investigated. Nevertheless, the automotive (and the transportation sector in general) and the biomedical sectors as well as architecture are still looking at this technology as a non-conventional forming technique with a still not sufficiently mature

check for updates

Citation: Sorgente, D. Superplasticity and Superplastic Forming. *Metals* **2021**, *11*, 946. https://doi.org/10.3390/met11060946

Received: 25 May 2021
Accepted: 10 June 2021
Published: 11 June 2021

knowledge to be largely adopted. Not mentioning the entire germane literature on the topic, it is out of question that further research efforts in this field are warranted.

The aim of this special issue is to provide a small but effective up-date on the advances in the research on superplasticity and on superplastic forming.

2. Contributions

In this special issue, published contributions cover several aspects of the topic related to superplasticity and superplastic forming. The investigated materials are well-known (but still promising) lightweight metal alloys, i.e., aluminium (Al), magnesium (Mg), and titanium (Ti) alloys.

In spite of decades of work on material characterization in the superplastic field, there is a strong debate on the most effective methodologies to find material parameters (and consequent process windows). Tensile tests are surely the most adopted methodology, since they allow deforming the material at a controlled strain rate without knowing its behaviour a priori. Nevertheless, several peculiar techniques with different strain and stress states have been developed in an attempt to assure effectiveness and accuracy in the characterization procedure. The first group of contributions to this special issue faces this precise sub-topic. The contribution by Aksenov and Mikolaenko [1] explores a wide range of materials by finite element (FE) simulations and, by doing that, reveals the strong influence of the material properties on the accuracy of results achieved in tensile tests in the superplastic field. In particular, the authors show the potential errors that could be made on the measurements of the strain rate sensitivity and on the strain softening. They conclude that data that are not directly measured during the tests should be checked by numerical simulations and refined by an inverse analysis. In their contribution, Guangwen, et al. [2] propose a constitutive model for Mg alloys that takes into account the grain growth and cavity formation. The model is calibrated by fitting data from free bulge tests and microstructure analyses. FE numerical results are compared with ones obtained by experimental forming tests on complicated real geometries. A close agreement between them is found, denoting the importance of considering microstructural phenomena in the constitutive modelling of superplastic materials. A sophisticated approach has been followed by Song, et al. [3] who, in their contribution, studied the deformation mechanisms of a Ti alloy and propose a constitutive model that takes into account a large number of microstructural phenomena such as dynamic recrystallization, grain growth as well as the change in the phases morphology. Those features together promote different deformation mechanisms and affect the stress hardening and softening of the material during the deformation process at different temperatures and strain rates. García-Barrachina and Gámez [4] gave their contribution to this special issue studying the behaviour of several different metal alloys (Zn-Al, Al, Pb-Sn, Mg, and Ti) and applying dimensional analysis to the superplastic deformation process. They propose an original way of approaching the superplastic characterization, unifying the material description into a single strain-rate dependent variable called apparent viscosity. In this way, the characterization task could be potentially done on a high-demanding material with a down-scaled model on a different material with lower requirements and costs.

Another group of contributions are focused on the grain refinement of Mg and Al alloys through severe plastic deformation. Figueredo and Langdon [5] show how high-pressure torsion introduced superplastic properties on a commercial Mg alloy at relative low temperatures and/or fast strain rates. The achieved grain-refined microstructure changes the deformation mechanisms producing higher tensile elongations than those in samples prepared using conventional thermo-mechanical processing. The contribution by Mikhaylovskaya, et al. [6] focused on the behaviour of a conventional Al–Mg-based alloy after processing it by isothermal multi-directional forging (IMF). They analysed the microstructure evolution during consecutive IMF passes and report that the achieved non-homogeneous grain structure does not allow a superplastic behaviour on the treated alloy. However, a subsequent cold rolling and an annealing process lead to a homogeneous microstructure and to high strain rate superplasticity as well as to an increase of the yield strength of the material at room temperature.

The last but not the least group of contributions to this special issue is more process-oriented and deals with the forming process of sheets and tubes. Majidi, et al. [7] contribute with a numerical study of the high-speed blow forming process on an Al automotive component. They quantify the effect of the size of the mesh element, of the coefficient of friction between the sheet and the die surfaces, and of the material constitutive model on the thinning predictions made by a FE model. They show how excessive thinning and the consequent fracture can be predicted only if a correct choice of the constitutive equation is made. The contribution by Trân, et al. [8] is focused on the hot gas forming process of Ti tubes for producing hollow profiles. By means of numerical simulations, the authors were able to identify a process window with an appropriate pressure profile for the manufacturing of sound parts, avoiding necking or wrinkling. Furthermore, they highlight some discrepancies between numerical results and experimental ones attributing such deviations to the material model highlighting, once more, the importance of material characterization in this field.

3. Conclusions and Outlook

When it comes to superplasticity and superplastic forming, material science and manufacturing science are intimately bound to each other. This special issue helps in corroborating this thesis and includes contributions on both investigation fields, giving the reader a small but intensive prospect of the research efforts currently made on this topic.

The reader can appreciate how the understanding and the modelling of the material behaviour is paramount in the forming process design and how new requirements in the industrial process are directing research efforts towards the development of new materials and new thermo-mechanical treatments. The (conventional and non-conventional) material characterization plays a very important role and allows for an efficient process window identification for translating research into industrial benefits. The numerical simulation is consolidating its usefulness in the understanding of material deformation behaviour as well as in the process design and validation, where it can now be considered an unavoidable step. Characterization in the superplastic field is mainly based on tensile tests but alternative testing procedures are attracting more and more interest. Industrial needs push material scientists and manufacturing experts to produce more efficient materials (e.g., ultra-fine grained metal alloys) with controlled microstructure. Further efforts in providing processing routes on commercially available metal sheets are needed to reach that goal. On the other hand, pseudo-superplastic or superplastic-like forming processes are part of one of the future trends to reach out further production sectors where manufacturing time and costs are of vital importance. The production of hollow parts starting with tubes or combining the superplastic forming with other forming and/or joining technique could give a boost to the exploitation of this manufacturing process.

The transportation and biomedical sectors are among those involving light metal alloys and/or complicated and highly customized geometrical features, establishing them on the path to a smarter application of superplastic forming. Social needs could motivate and benefit these envisaged developments, lowering the environmental impact in production, the manufacturing process, and the circular economy.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Aksenov, S.; Mikolaenko, V. The effect of material properties on the accuracy of superplastic tensile test. *Metals* **2020**, *10*, 1353. [CrossRef]
2. Dai, G.; Jarrar, F.; Ozturk, F.; Sheikh-Ahmad, J.; Li, Z. An Accurate Constitutive Model for AZ31B Magnesium Alloy during Superplastic Forming. *Metals* **2019**, *9*, 1273. [CrossRef]
3. Song, L.; Ii, A.; Despax, L.; Onishi, H.; Matsumoto, H.; Velay, V.; Vidal, V. Experimental analysis and behaviour modelling of the deformation mechanisms of a Ti-6242S alloy under hot and superplastic forming conditions. *Metals* **2020**, *10*, 1599. [CrossRef]

4. García-Barrachina, L.; Gámez, A.J. Dimensional analysis of superplastic processes with the buckingham Π theorem. *Metals* **2020**, *10*, 1575. [CrossRef]
5. Figueiredo, R.B.; Langdon, T.G. Using high-pressure torsion to achieve superplasticity in an az91 magnesium alloy. *Metals* **2020**, *10*, 681. [CrossRef]
6. Mikhaylovskaya, A.V.; Kotov, A.D.; Kishchik, M.S.; Prosviryakov, A.S.; Portnoy, V.K. The effect of isothermal multi-directional forging on the grain structure, superplasticity, and mechanical properties of the conventional al–mg-based alloy. *Metals* **2019**, *9*, 33. [CrossRef]
7. Majidi, O.; Jahazi, M.; Bombardier, N. Finite element simulation of high-speed blow forming of an automotive component. *Metals* **2018**, *8*, 901. [CrossRef]
8. Trân, R.; Reuther, F.; Winter, S.; Psyk, V. Process development for a superplastic hot tube gas forming process of titanium (Ti-3Al-2.5V) Hollow profiles. *Metals* **2020**, *10*, 1150. [CrossRef]