metals

MDPI

Editorial

Material and Process Design for Lightweight Structures

Talal Al-Samman

Institute of physical metallurgy and metal physics, RWTH Aachen University, Kopernikusstr. 14, 52074 Aachen, Germany; alsamman@imm.rwth-aachen.de

Received: 29 March 2019; Accepted: 4 April 2019; Published: 6 April 2019

1. Background

The ever-rising demand for increased fuel efficiency and a reduction in the harmful emission of greenhouse gases associated with energy generation and transportation has led, in recent years, to a resurgence of interest in light materials and new lightweight design strategies. In the automotive industry, the need to reduce vehicle weight has given rise to extensive research efforts to develop aluminum and magnesium alloys for structural car body parts. In aerospace, the move toward composite airframe structures urged an increased use of formable titanium alloys. In steel research, there are also major ongoing efforts to design novel damage-controlled forming processes for a new generation of efficient and reliable lightweight steel components. All of these materials, and more, constitute today's research mission for lightweight structures. They provide a fertile materials science research field aiming to achieve a better understanding of the interplay between industrial processing, microstructure development, and the resulting material properties.

Given the extensive scientific and technological importance of this timely subject, this Special Issue on "Material and Process Design for Lightweight Structures" was dedicated to collect concise reports on the current status in the field. The topics discussed herein include areas of manufacturing and processing technologies of materials for lightweight applications, innovative microstructure and process design concepts, advanced characterization techniques combined with modeling of materials behavior.

2. Contributions

The first article [1] is concerned with quantifying and minimizing damage in the complex microstructure of dual-phase steels. The study developed from a close and fruitful collaboration between the RWTH Aachen University and the Technical University of Dortmund within the context of the Collaborative Research Centre CRC/Transregio 188 "Damage-Controlled forming processes" supported by the German Research Foundation. The authors report outstanding technological advance on two fronts; In terms of (i) damage-reduced bending methodology (stress-superposed bending) and (ii) automated damage quantification of large micrographs of the order of a mm^2 at high resolution by means of panoramic imaging within a scanning electron microscope. A reduction of deformation-induced damage during processing of advanced high strength steels contributes greatly to lightweight design by allowing to offset material weight via the realization of thin-walled sheet metal parts while maintaining their mechanical performance.

The second of this set of articles is a featured paper by R. Kulagin et al. marking international research efforts between Germany, Ukraine and Australia in the area of severe plastic deformation (SPD) technologies and ultrafine-grained architectured materials [2]. The authors propose, for the first time, an analytical model capable of determining optimal deformation parameters and calculating the equivalent strain distribution over the entire sample length during the high pressure torsion extrusion process. This technique has the advantage over conventional high pressure torsion of being able to process long samples in a semi-continuous way, which is considered an exceedingly promising next step towards industrial upscaling of SPD. Owing to the simplicity and robustness of the presented theoretical approach, the authors reckon it can be successfully applied to calculating the mechanical behavior of lightweight structures made of magnesium, aluminum, and titanium.

In the third contribution [3], G. Cornacchia et al. present an innovative approach to further expand the field of application of high pressure die casting. This technology combines many advantages being able to produce thin-walled components, at low costs and high production volumes. The main limitation, however, is the difficulty to cast complex hollow components by the use of lost cores that are able to endure the high pressures used in the process. In this regard, the authors combine numerical and experimental research work to develop and utilize new ceramic cores that allow the production of an improved aluminum crossbeam for passenger cars. The study shows a promising avenue to implement this new technology for other safety relevant automotive hollow component.

B. Zhu and co-workers [4] provide an important insight of lightweight design into another field of applications, namely electrical transmission fittings, which are conventionally manufactured from cast or forged steel as heavyweight thick parts. The work demonstrates a new multilayered-sheet hot stamping process used to produce an electric-power-fitting product. The key challenge was to determine the optimum combination of the number of sheet layers and the contact pressure because of their significant effect on the final microstructure and mechanical properties. From numerous performance tests, a successful approach of using double-layered sheets was derived, achieving a fully martensitic microstructure at a relatively low contact pressure. The fabricated new component met the required standards for mechanical properties and load capacity, and exhibited a fantastic weight reduction of 60%.

The fifth contribution by S. Yi and co-workers from Helmholtz-Zentrum Geesthacht and Korea Institute of Materials Science is concerned with aspects of texture and microstructure control of a new non-flammable Mg-Al-Zn-Y-Ca (AZXW3100) magnesium sheet alloy, with the main goal of enhancing the ductility and formability at ambient temperatures [5]. The authors conducted a systematic investigation of the effect of the rolling temperature and imposed deformation per pass on weakening the basal texture and refining the microstructure during subsequent annealing treatments. Their findings clearly suggest that a rolling temperature of 450 °C and an increasing strain per pass (from 0.1 to 0.3) up to 11 passes, combined with following short 400 °C annealing can deliver a highly ductile and formable sheet exhibiting a remarkable Erichsen index of 8.1. Such huge success has significant implications for sheet metal forming perspectives, particularly in the automotive and aircraft industries, where modern, competitive magnesium alloys, due to their excellent strength-to-weight ratio, are becoming increasingly popular.

In "Effect of Surface Roughness on the Bonding Strength and Spring-Back of a CFRP/CR980 Hybrid Composite" [6], J.-H. Hwang et al. cover a critical subject in the field of lightweight hybrid composite materials, where they discuss possible improvements in the interfacial bonding behavior between the CFRP and the metallic material, and the springback response after forming by means of V-bending tests. Surface treatment experiments and lap shear adhesion tests were conducted to investigate the change in the bonding strength as a function of surface roughness, bonding pressure, compressive force, and compression direction. The results show a visible trend of increasing bonding strength with increasing surface roughness up to an optimal value, after which the occurrence of voids cause a fatal decrease in bond strength.

With a view to design connected processing steps that ensure viable manufacturing of lightweight components at high speeds, Rao et al. employed processing maps to investigate the hot working behavior of a new creep-resistant Mg–4Al–2Ba–2Ca alloy [7]. They report that in the as-cast condition, the alloy has a limited workability due to the presence of a large volume of intermetallic phases at the grain boundaries. To solve this problem, they introduced a connected step of extrusion, which helped greatly in refining the grain size and the particle distribution. They nicely show that the processing map for the extruded alloy exhibits a reduced flow instability regime, and a much more attractive workability window, characterized by suitable working temperatures to achieve a fine grain size, and sufficiently high strain rates to enable manufacturing at viable speeds.

The article by X. Xue et al. [8] fills another knowledge gap related to the sophisticated production of hollow, thin-walled aluminum alloy profiles, used for example in the bodies of high speed trains. The challenging aspect of extruding such profiles lies in their complex cross sections, which renders material flow in the extrusion die cavity much complex and difficult to control. As a result, the extruded parts are often liable to major defects leading to twisted or distorted profiles. Via numerical simulations and validation experiments, the authors present an optimum design of a die structure used in a multi-output porthole extrusion process, developed to reduce the forming load and improve the product quality. The current research provides a useful direction for obtaining a balanced metal flow behavior with uniform extrusion velocity that leads to minimizing extrusion defects of complex aluminum profiles during porthole die extrusion.

The important topic of fatigue and fracture behavior was also covered in this special issue by L. Zhan et al. in "Effect of Process Parameters on Fatigue and Fracture Behavior of Al-Cu-Mg Alloy after Creep Aging" [9]. The aim of the study was to analyze the effects of different creep aging parameters on the creep behavior, mechanical properties, and fatigue fracture behavior of a widely used Al-Cu-Mg alloy in the aerospace industry in order to advance the development of creep aging treatments of this class of aluminum alloys. The findings suggest that an increase of temperature and stress improves the creep response and fatigue life of the alloy up to a certain extent, which is then followed by a deterioration of these properties if the temperature and stress continue to increase. With the help of transmission electron microscopy, the authors conclude that the transition in properties is due to modified precipitation characteristics, and provide a clear concept on how to tune the microstructure to achieve optimal creep aging performance.

Finally, in the last article [10], K. Zheng et al. address the performance of in-die quenching during hot stamping of AA6082 aluminum alloy by means of systematic experimental and analytical investigations. The conducted work marks out numerous influencing factors, such as the initial work-piece and die temperatures, quenching pressures, work-piece thickness, and die clearances. The results revealed that the in-die quenching efficiency can be significantly enhanced by decreasing the initial work-piece and die temperatures. The authors also note that die clearances need to be carefully designed in order to obtain sufficiently high quenching rates and satisfying strength of hot-stamped panel components. The study provides useful, practical insights into designing manufacturing processes of hot stamping parts for mass production.

3. Concluding Remarks

As a Guest Editor of this special issue of Metals I greatly enjoyed reading and learning so much from the above mentioned articles. The broad scope of contributions and accomplishments is truly remarkable, and emphasizes the wide variety of topics that could and should be treated under this rapidly-growing and far-reaching subject. I hope that with this special issue we were able to provide the readers with a sense of where significant advances are being made, where critical issues remain pending, and, from the authors' perspectives, where the field is heading in the near future.

Acknowledgments: The guest editor would like to express his deepest appreciation to all the authors who contributed their research to this special issue. I also want to thank all the reviewers for their extremely valuable and timely feedback that allowed all the authors to push the quality of their contributions to a higher level. Special thanks to Ms. Betty Jin and the editorial staff for their enduring efforts in bringing this special issue together. Last but not the least, the Guest Editor is very grateful for continual financial support from the Deutsche Forschungsgemeinschaft (DFG) through numerous research grants within the field of lightweight material and process design.

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

References

1. Meya, R.; Kusche, C.F.; Löbbe, C.; Al-Samman, T.; Korte-Kerzel, S.; Tekkaya, A.E. Global and High-Resolution Damage Quantification in Dual-Phase Steel Bending Samples with Varying Stress States. *Metals* **2019**, *9*, 319. [CrossRef]
2. Kulagin, R.; Beygelzimer, Y.; Estrin, Y.; Ivanisenko, Y.; Baretzky, B.; Hahn, H. A Mathematical Model of Deformation under High Pressure Torsion Extrusion. *Metals* **2019**, *9*, 306. [CrossRef]
3. Cornacchia, G.; Dioni, D.; Faccoli, M.; Gislon, C.; Solazzi, L.; Panvini, A.; Cecchel, S. Experimental and Numerical Study of an Automotive Component Produced with Innovative Ceramic Core in High Pressure Die Casting (HPDC). *Metals* **2019**, *9*, 217. [CrossRef]
4. Zhu, B.; Zhu, Z.; Jin, Y.; Wang, K.; Wang, Y.; Zhang, Y. Multilayered-Sheet Hot Stamping and Application in Electric-Power-Fitting Products. *Metals* **2019**, *9*, 215. [CrossRef]
5. Yi, S.; Victoria-Hernández, J.; Kim, Y.; Letzig, D.; You, B. Modification of Microstructure and Texture in Highly Non-Flammable Mg-Al-Zn-Y-Ca Alloy Sheets by Controlled Thermomechanical Processes. *Metals* **2019**, *9*, 181. [CrossRef]
6. Hwang, J.; Jin, C.; Lee, M.; Choi, S.; Kang, C. Effect of Surface Roughness on the Bonding Strength and Spring-Back of a CFRP/CR980 Hybrid Composite. *Metals* **2018**, *8*, 716. [CrossRef]
7. Rao, K.; Chalasani, D.; Suresh, K.; Prasad, Y.; Dieringa, H.; Hort, N. Connected Process Design for Hot Working of a Creep-Resistant Mg–4Al–2Ba–2Ca Alloy (ABaX422). *Metals* **2018**, *8*, 463. [CrossRef]
8. Xue, X.; Vincze, G.; Pereira, A.; Pan, J.; Liao, J. Assessment of Metal Flow Balance in Multi-Output Porthole Hot Extrusion of AA6060 Thin-Walled Profile. *Metals* **2018**, *8*, 462. [CrossRef]
9. Zhan, L.; Wu, X.; Wang, X.; Yang, Y.; Liu, G.; Xu, Y. Effect of Process Parameters on Fatigue and Fracture Behavior of Al-Cu-Mg Alloy after Creep Aging. *Metals* **2018**, *8*, 298. [CrossRef]
10. Zheng, K.; Lee, J.; Xiao, W.; Wang, B.; Lin, J. Experimental Investigations of the In-Die Quenching Efficiency and Die Surface Temperature of Hot Stamping Aluminium Alloys. *Metals* **2018**, *8*, 231. [CrossRef]