HEALFORM project

An hybrid experimental/numerical strategy for void **heal**ing prediction during hot metal **form**ing processes

Context

In a particularly critical environmental context, designing new mechanical components for industry demands low-energy manufacturing solutions that deliver high mechanical performance and enhanced sustainability. To address this challenge, the **HEALFORM** project aims to develop a modeling strategy focused on eliminating porosity-related defects, thus producing components with superior mechanical properties and extended lifespans.

Following casting, metal ingots may contain voids of varying shapes and sizes, which must be eliminated to achieve a sound material. Hot metal forming processes are commonly employed in the industry to address this issue, but calibrating these processes to ensure complete closure of internal voids and final healing of the material remains a challenge. A first PhD, initiated in 2024, focuses on understanding the void closure kinetics during metal forming processes. This new PhD opportunity, part of the **HEALFORM** project, aims to **develop an experimental device and advanced measurement techniques to study void healing once the voids are closed, with each side of the surfaces in contact.**

This project combines cutting-edge experimental and numerical research with significant industrial expectations. It is funded through an industrial consortium that includes two steel suppliers, ACM and ArcelorMittal, as well as a software company, Transvalor.

PhD Program

After casting, hot rolling processes help close existing voids. However, to ensure the quality of the produced materials, it is crucial to verify that these closed voids have fully healed. This healing mechanism is influenced by several factors, including processing temperature, compression strain, and holding time. However, determining the exact moment when healing has truly occurred remains a significant challenge [1 - 5]. The PhD program will focus on two main objectives:

1. **Development of a dedicated in-house thermomechanical healing test**, where temperature, compressive load, and holding time can be precisely controlled. This will require specific experimental advancements, particularly in the heating system (e.g., induction or lamp heating) and in the methodology for detecting when healing has been achieved. Additionally, microstructural observations will be conducted to analyze potential recrystallization at the void surfaces in contact.
2. **Definition and implementation of a healing model** that incorporates the influence of the aforementioned process parameters. This model will be integrated into the void closure model currently being developed in an ongoing PhD project in collaboration with the same industrial partners. Numerical simulations will be carried out on the finite element software Forge® and will be validated with respects to experiments.

Within this PhD, special attention will be given to surface quality and preparation to prevent oxidation at void interfaces.

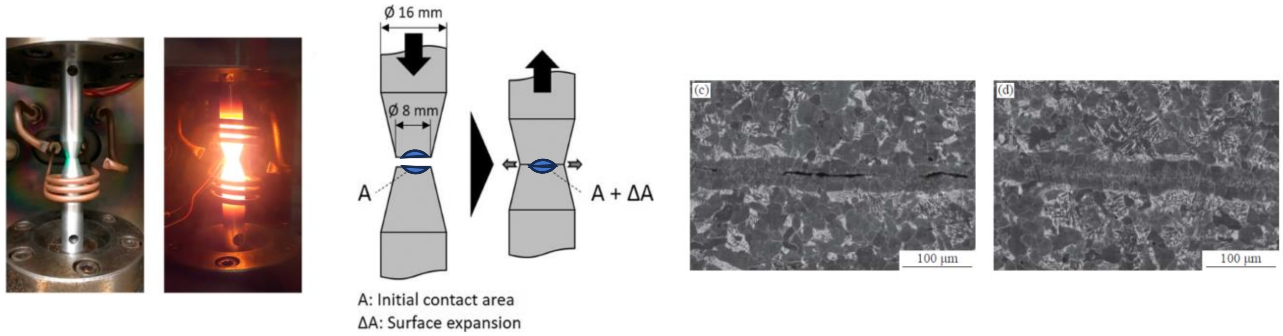

Figure 1. Example of thermomechanical void healing characterization tests [1, 3] and observation of the healed interface [4]

Benefits & Candidate profile

This PhD offers a unique opportunity to develop cutting-edge thermomechanical experiments alongside a fully integrated numerical model, with critical applications in the metal forming industry. Leveraging the internationally recognized expertise and complementary skills of the project partners, the research is expected to lead to several high-impact scientific publications. The strong involvement of industrial partners from the steel and software industries ensures a focus on practical, industry-driven applications across multiple sectors.

The ideal candidate should hold a Master's degree in mechanics, materials science, or a closely related field. A **strong interest in designing and developing dedicated thermomechanical experiments is essential**. Prior experience with finite element simulations in material forming would be a valuable asset.

Partnership

The PhD project is funded jointly by **Transvalor** (a software company leader in material forming) **and ACM Acciaierie Bertoli Safau** (a steel producer) and in collaboration with ArcelorMittal. The PhD will be carried out at CEMEF (**Center for Material forming of MINES Paris PSL)**, and in collaboration with **LCFC at ENSAM Metz**. The candidate will be awarded a PhD degree from **Mines Paris PSL**.

PhD Supervisors: Prof. P.-O. Bouchard, Dr. D. Pino Munoz, Dr. L. Langlois and Dr. M. Durand

Applications

Applications must include a detailed CV, transcripts from the past two years, and one or two letters of recommendation.

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References

[1] P. Hibbe and G. Hirt, Analysis of the bond strength of voids closed by open-die forging, International Journal of Material Forming, 2019

[2] X. Li, C. Liebsch, G. Hirt, J. Lohmar, Modelling of void healing in hot rolling due to recrystallization, Production Engineering (2020) 14:43–52

[3] D. Czempas, C. Liebsch, G. Hirt, Integration of a void healing criterion in multi-scale modeling of hot rolling, *Advances in Industrial and Manufacturing Engineering*, Volume 8, 2024.

[4] Z.-H. Gao, W. Yu, *X. Chen*, *B.-S. Xie*, *and Q.-W. Cai,* Effect of gradient temperature rolling process on promoting crack healing in Q500 heavy plates*, International Journal of Minerals*, *Metallurgy and Materials, Volume 27*, *Number 3*, *March 2020*, *Page 354*

[5] M. Qin, J. Liu, J. Li, and X. Zhang, A study of the void surface healing mechanism in 316LN steel, High Temperature Materials and Processes 2023; 42: 20220282