How Does the Surface Tension of Steel Change at High Temperatures?

Dr Jörg Volpp

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In a recent study, Dr Joerg Volpp from University West, Trollhättan, Sweden, redefined our previous understanding of the surface tension of steel at extreme temperatures. His important insights could improve industrial manufacturing processes like welding and additive manufacturing, as well as offer exciting theoretical implications.

Surface Tension and Materials Science

The concept of surface tension plays a pivotal role in materials science, especially when it comes to understanding how liquids interact with themselves and with other materials. Simply put, surface tension is the elastic tendency of a fluid's surface, acting like an invisible skin that influences how liquids form droplets, bubbles, or spread on surfaces. You may have noticed it when looking at flies or small insects being able to 'walk on water'. This principle holds profound implications for various industrial processes, particularly those involving metals – such as steel – in their molten state.

Steel transforms into a liquid at high temperatures, and its interactions at this juncture are governed largely by surface tension. Understanding these interactions is key to optimising manufacturing processes, ensuring quality, and pushing the boundaries of what these techniques can achieve. For instance, in welding, the fluid dynamics of molten steel can affect the strength and finish of the weld. At the same time, in additive manufacturing, it influences the precision and reliability of the parts being produced.

Historically, however, there has been a significant knowledge gap in our understanding of steel's surface tension at high temperatures. Traditional methods of studying these properties have often fallen short, largely due to the difficulty of obtaining accurate data in extreme conditions.

How Surface Tension Changes with Temperature

Dr Joerg Volpp from University West conducted a detailed examination to uncover new insights about steel's surface tension at high temperatures. The experiment began with the careful selection and preparation of steel samples, which were cleaned to ensure purity for accurate results. The researcher then set up a sophisticated system, including a laser for heating the steel to a molten state and cameras for visual high-speed recording and temperature measurement.

To start, the researchers calibrated their high-speed and RGB cameras – essential tools for capturing the dynamics of molten steel and measuring its temperature based on the colour of its glow. The RGB camera captures the precise colour of the molten metal, which in turn depends on the temperature. Indeed, hot metals radiate light – this is how old lightbulbs work! The colour depends on the temperature and, therefore, it is possible to deduce one from the other. This method provides a non-intrusive way to measure the high temperatures of molten steel.

With everything in place, the laser was directed at the steel samples, heating them until they melted. As the steel reached molten form, the high-speed camera recorded the capillary waves on its surface, capturing the details of their movement. Simultaneously, the RGB camera monitored the glowing steel, allowing the team to deduce its temperature.

Following the recordings, the researchers analysed the data, focussing on the patterns and behaviours of the surface waves captured by the high-speed camera. By correlating these observations with the temperature data from the RGB camera, they could better understand how surface tension changes with temperature.

A Significant New Discovery

Their experiments revealed a significant finding: the surface tension of steel decreases much more steeply with an increase in temperature than previously understood. Based on linear extrapolations from lower temperature data, traditional beliefs suggested a more gradual decline. However, Dr Volpp's research indicates that as the temperature ascends beyond the melting point, the decline in surface tension accelerates, deviating from earlier predictions.

The implications of this discovery are not fully clear, but certainly important. Indeed, any industry that relies on processing molten steel should now be able to tweak its machinery to achieve better results in light of the newly discovered behaviour.

In welding, for example, the fluid dynamics of the molten material, influenced by surface tension, are crucial for achieving the desired strength and finish in the welds. The team's findings suggest that adjustments to welding parameters might be necessary to accommodate the more rapid changes in surface tension.

Similarly, in the realms of cutting and additive manufacturing, understanding the precise behaviour of molten steel at high temperatures can improve the final product's process accuracy and material properties.

Science: Observing, Learning, Adapting

Further, the theoretical ramifications of this research extend beyond immediate industrial applications. By providing a more accurate model of steel's surface tension at high temperatures, Dr Volpp's work expands existing theories, posing questions that demand answers.

The scientific method is about learning and adapting. When experiments provide unexpected data, it tells us that our current understanding isn't the whole story. This doesn't mean we were completely wrong before; indeed, previous theories were usually validated by predictions – but it just means there's more to learn. This cycle of observing, learning, and updating is how science gets better over time. It reminds us that science is always on the move, improving with each new piece of evidence we find.

Dr Volpp's work is a perfect example of this – a discrepancy was found between the models suggested in the literature, being linear, and the actual behaviour of molten steel when investigated carefully.

A new theoretical model is proposed in light of these new findings. It begins with constructing a simplified representation of a steel system at an atomic level, arranging iron atoms in a cubic lattice to mimic the structure of molten steel. This arrangement allows for the simulation of interactions among atoms, considering their movements and the forces acting between them. The model uses the Lennard-Jones potential, a fairly simple formula describing the potential energy between a pair of atoms as a distance function. This is introduced to mimic interactions between atoms: while not fully accurate, neglecting to consider several microscopic forces, it is enough to predict the general trend of the simulation.

In the model, temperature influences the strength of atomic interactions and their spatial arrangement. As the temperature was adjusted within the simulation, the software recorded the dynamics of the atomic interactions.

By comparing these simulation results with their experimental observations, Dr Volpp validated the exponential relationship between surface tension and temperature in their model, matching the experimental data and opening the way to developing a more accurate model of molten steel.

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Exciting New Questions

The study suggests that what we've found about steel might also apply to other metals, opening up possibilities for new research. It also makes us think differently about what's happening inside metals when they melt. This work has opened up many exciting new questions that could revolutionise the processes that involve hot metals. .

MEET THE RESEARCHER

Dr Jörg Volpp, University West, Sweden

Dr Jörg Volpp, Associate Professor in Production Engineering at University West, Sweden, is at the forefront of laser materials processing and additive manufacturing research. With a career that began in 2011, Dr Volpp has significantly contributed to our understanding of dynamics and stability during laser deep penetration welding, a key area within manufacturing engineering. His expertise encompasses a broad spectrum of laser-based manufacturing processes, including the behaviour of molten steel at high temperatures, which is pivotal for improving techniques such as welding and additive manufacturing. Dr Volpp strongly emphasises experimental research and simulation models in his work, effectively bridging the gap between theoretical predictions and practical applications in industrial manufacturing..

CONTACT

jorg.volpp@hv.se

https://ltu.diva-portal.org/smash/person.jsf?pid=authority person%3A70561&dswid=2279

Joerg Volpp – University West | LinkedIn

KEY COLLABORATORS

Professor Alexander Kaplan, Luleå University of Technology, Sweden

Professor Frank Vollertsen, University of Bremen, Germany

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FURTHER READING

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