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Article / Book Information

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Authors	Motoki Sakaguchi
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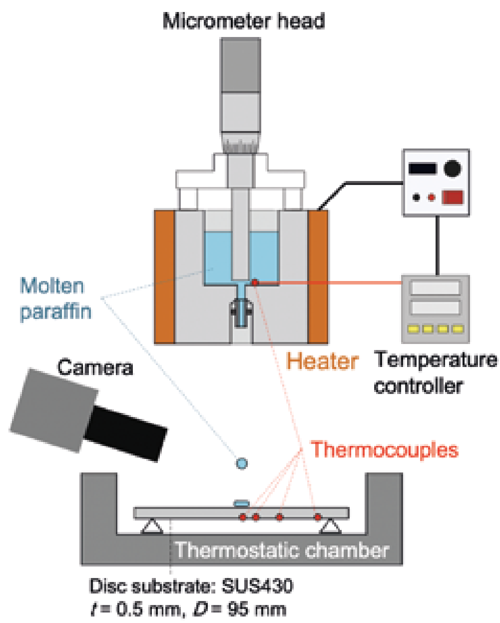
Impact Objectives

- Explore the mechanics of materials and fracture mechanics, especially for high temperature materials
- Research coating systems used in jet engine applications and land-based power generation

Experimental set-up for the model experiment in this project



A spotlight on materials strength and stress

***Associate Professor Motoki Sakaguchi**, from the **Tokyo Institute of Technology**, discusses his work investigating the phenomena of damage to materials used in high-impact industries such as transport and energy*

How did you become involved in researching material sciences?

My research interest is in the mechanics of materials and fracture mechanics, especially for high temperature materials such as nickel-based (Ni-base) superalloys, titanium-aluminium (Ti-Al) alloys. I am also interested in coating systems used in jet engine applications and land-based power generation.

In your laboratory you focus on researching actual phenomena associated with the fracture or deformation of the material subjected to forces, as well as material strength studies such as fracture mechanics and elastic-plastic mechanics. Why is this important information to learn more about?

The failure of materials, which is highly influenced by the mechanical properties of those materials, is a key factor limiting the service life of industrial components and structures. Clarifying the mechanisms of material failure is necessary in predicting the lifespan of industrial products under various operational environments and conditions. Our work therefore also has practical value in optimising manufacturing processes and designing new materials. This in turn helps in the production of high-performance and high energy efficiency industrial products. Expanding on our knowledge of the phenomena underlying how and why things go wrong with materials in industrial settings can help us not only develop better materials in the long run but can also help in predicting and preventing accidents that occur as a result of damage to materials.

In what way does this work help to develop design guidelines for the design of reliable materials and structures?

This work uses a novel experiment to study stress evolution and fracture behaviours in coating structures that are widely used in turbine blades, automotive engines and power generation system equipment. Our research on this project provides an in-depth understanding of several fracture phenomena during the manufacturing processes of coatings and reveals the effects of several manufacturing conditions on the reliability of the coatings produced. Our findings can help to optimise the practical coating processes and therefore contribute towards improving the reliability and performance of related products.

What is the ultimate impact of your studies?

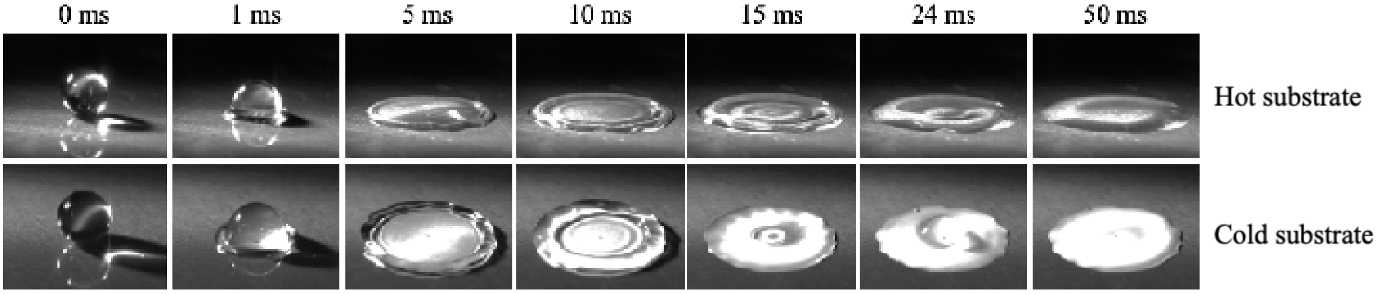
In this study, we first developed an original methodology to investigate and examine the manufacturing processes used in producing thermal sprayed coatings at the splat level. The method presents many possibilities that can be applied across research fields that are involved with splat deposition.

The phenomena of single splats are usually difficult to observe and investigate in the field of thermal spray. Our work provides a possible method to study the process of splat deposition, especially in stress evolution and fracture. We have also developed a new research method that may be useful to researchers and engineers working in other fields such as casting, welding, cold spraying, ink-jet printing and additive manufacturing.

Can you talk about your collaborations with other academic institutions or industry, and the importance of these to your research?

Collaboration in research is important in many fields and ours is no different. We are always open to forging new partnerships with other researchers. We are especially looking to touch base with researchers or institutions who have professional skills relating to the numerical simulation of fluid dynamics. We'd welcome contact from anyone in this area, particularly if they would like to work with us on this exciting project! ▶

High speed images of the impact and spread of HNP-9 droplet on hot and cold substrates



Investigating splat deposition

A team of researchers at the ***Tokyo Institute of Technology*** *has developed a novel experimental model to help investigate stress and strain evolution in coating materials*

Few of us perhaps consider the importance of coatings used in materials we come across every day. However, in industrial applications, such as aeronautics and power plants, understanding how stresses and strains evolve during the solidification and adhesion of coating material production is vital to ensure that critical equipment performs to required standards. At the Tokyo Institute of Technology in Japan, researchers in the Inoue Sakaguchi Laboratory have been developing new techniques to study the fracture and elastic-plastic mechanics of coating materials.

'We have been focusing on stress and strain evolution during the solidification and adhesion process of coating material, based on the model experiments using paraffin wax,' says Associate Professor Motoki Sakaguchi, a leading member of the team working on this project. 'The proposed model experiment is so simple that we can easily investigate individually the effects of many kinds of experimental variables including droplet materials, droplet temperature, droplet kinetic energy, substrate temperature and substrate roughness,' he says.

Sakaguchi's current project centres on investigating the fundamental processes involved in residual stress development in thermal barrier coatings during thermal spray procedures. These coatings are always used in many industrial components to add thermal, wear, erosion or corrosion resistance. However, residual stress significantly affects the reliability and longevity of thermal barrier coatings, and the value of this residual stress is directly related to the deposition of single splats during the manufacturing process. 'The residual stress originates from a single splat deposition, so it is very difficult to measure due to the small size and high velocity of splats in the thermal spray,' explains Sakaguchi. The model experiment that his team has developed helped them to simplify the thermal spray using a paraffin wax with a low melting point. This has enabled them to monitor and precisely record the deposition process of each splat.

NEW METHODOLOGY, BETTER MATERIALS

This project is generating important data on the fracture behaviours of thermally sprayed coatings at the splat level. This is vital in elucidating the basic mechanisms behind the failures of important components. Not only will this work help in improving thermal spray technology, but it will inevitably lead to better, longer-lasting components and equipment in industrial products.

One critical part of the work accomplished by Sakaguchi and his team is the development and use of the model experiment using paraffin wax. As the material used in the model experiment is different to those used in real life applications, it is necessary for the group to validate their research findings to ensure that their results are applicable to materials used in real industrial settings. Thus, with each set of new data they obtain, Sakaguchi and his team carry out comprehensive comparisons with results obtained by other groups, particularly targeting results from teams working on actual industrial applications. They also confirm the reproducibility of their experiments by repeating them under the same conditions.

EXPLORING SOLUTIONS

The motivation for initiating this research project stemmed from the desire to clarify several engineering questions about the technology used in thermal spraying. While the phenomena being investigated in the model experiments are simple, there are also complicated multi-physics involved, covering fluid dynamics, thermo-dynamics and mechanics of material. 'We learned from this research that a comprehensive understanding is required to solve a simple problem,' says Sakaguchi.

Sakaguchi and his team are dedicated to elucidating fracture mechanisms and finding ways in which to improve the service life of thermally sprayed coating systems. 'The experiment in this study and related industrial applications cover many common phenomena and theories even though the model experiment cannot consider all the factors involved in the real world,' states

Sakaguchi. However, he believes that their findings can help provide valuable information for improving thermal spray manufacturing processes.

The use of paraffin wax in the simplified model they have developed made it possible to simulate the thermal spray process. This represents a breakthrough in techniques used to investigate the processes used in manufacturing coatings. Their experiment methodology is not only replicable but also easy to set up and carry out, enabling researchers to precisely record the whole entire splat deposition process. 'We were pleased to have been able to reproduce almost all splat fracture behaviours during thermal spray processes using the model experiment,' highlights Sakaguchi. This included such behaviours as cracking, delamination and debonding. They were also able to use these simulations to explain the genesis of these fractures.

> *'The proposed model experiment is so simple that we can easily investigate individually the effects of many kinds of experimental variables'*

SUPPORTING SCIENCE AND INDUSTRY

Looking forward, the team hopes to build on their current work over the next few years. Although they have been happy with their progress so far, there are still several unanswered questions that they intend to clarify in order to expand on existing knowledge in this area. 'First of all, we will try to extend this study to the field of fluid mechanics,' enthuses Sakaguchi. 'The primary purpose is to numerically predict the impact process of splats on the substrate, which can help to predict and control the geometry of deposited splats,' he adds. As their laboratory's key focus is on solid mechanics research, this will be a challenging goal of the team. Fluid mechanics is a relatively new area for them, and they are looking for new collaborators with expertise in these areas to help them progress in this direction.

Studying the evolution of stress on a micro and/or nanometre level will also be an area in which they hope to make progress. They are, for example, intending to study the fluid-solid interaction at interfaces and how their effect on stress and fractures impact on materials. A dual experimental as well as statistical approach will be used to observe and analyse these results.

Sakaguchi has published a number of articles on this topic. His most recent contribution was published in Surface & Coatings technology in 2020 with colleagues Professor Hirotsugu Inoue and Dr Chao Kang on the 'contribution of creep to strain evolution in a paraffin droplet during and after rapid solidification on a metal substrate'. He has also published articles in 2019 on 'quenching stress and fracture of paraffin droplet during solidification and adhesion on metallic substrate', and in 2017 on the 'measurement of quenching strain in paraffin drop test modelling thermal spray process'.

The continuation of Sakaguchi's group's work could have a profound impact on the longevity of key components used in a variety of real-world applications, as well as improving on the manufacturing processes used in producing these key parts. Additionally, not only does their work promise to reap benefits for materials science applications in a variety of industries, but their work on developing new experimental models and methodology has also helped promote better tools for researchers in their own and related fields of study. This team's efforts are well worth following for their contribution to science and to industry. ●

Project Insights

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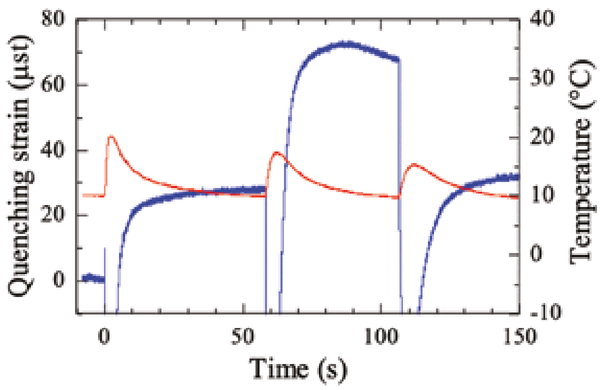
COLLABORATORS
• Professor Hirotsugu Inoue, Tokyo Institute of Technology
• Dr Yoshifumi Okajima, Mitsubishi Heavy Industries Ltd

TEAM MEMBERS
Tokyo Institute of Technology - Assistant Professor Yu Kurokawa, Dr Chao Kang, Junyao Zhou, Akito Saito, Ayumi Amano

CONTACT
Associate Professor Motoki Sakaguchi

T: +81 3 5734 2841
E: sakaguchi.m.ac@m.titech.ac.jp
W: http://www.ichizai.mep.titech.ac.jp/index_en.html

BIO
Dr Motoki Sakaguchi is an Associate Professor in the Department of Mechanical Engineering, Tokyo Institute of Technology. Sakaguchi was a visiting professor at the University of Siegen supported by the Alexander von Humboldt Foundation in Germany. He was awarded the JSMS Award for Scientific Paper in 2006, the JSMS Award for Promising Researchers in 2018, The Young Scientists' Prize in MEXT in 2019 and a JSME Medal for Outstanding Paper in 2019 and 2020.



Evolution of residual strain and temperature during impact, solidification and cooling of paraffin droplet