Role of Overseas R&D in Expanding Global Automotive Business

George Saikalis Harsha Badarinarayan Yoichi Sugita

OVERVIEW: In the recent past, there has been a strong initiative within Hitachi to expand our business to a much broader, more diverse, and emerging global market. The Hitachi Automotive Division is one such business group that sees the potential to diversify our customer portfolio globally so that we are competitive in markets that we have not explored in the past. In this regard, strong collaboration with overseas R&D will be the key for fast product development, quicker time-to-market, and the building of stronger relationships with local customers. There is an effort to form a 'Global One Team' within Hitachi comprising R&D facilities around the world, including in Japan, Europe and the USA, that will enable business units in those geographical locations to accelerate their product development and be at the cutting edge of technology by providing solutions for site-specific issues through organic growth and collaborations with leading universities. This article gives an overview of our current global R&D activities in some of these overseas labs, highlighting our key technologies and long-term commitment to our customers.

INTRODUCTION

THE aim of realizing a truly global Hitachi operation would require the different entities, including both business groups and research and development (R&D) facilities, that are spread across the globe to be aligned towards a common goal. In order to transform the 'strong business in Japan' into a 'winning business in the global market,' to achieve the targets set out in the 2015 Mid-term Management Plan, and to drive the strategic growth of the Hitachi Group, it is essential that concrete measures be taken to enhance collaboration between overseas and domestic business and R&D.

This article describes R&D activities in the area of automotive technology that are being carried out in Europe and the USA. The final goal of 'global' collaboration is that technology should be made available to all Hitachi group companies, regardless of where it is developed, to ensure efficient use of resources and to enhance the capabilities of each R&D facility through collaboration.

RESEARCH ACTIVITY IN EUROPE (TEEL/AUTOMOTIVE)

The Transportation, Energy and Environment Research Laboratory (TEEL) was established in October 2005 and has offices in Germany and the UK. TEEL's mission is to support automotive, train, and energy businesses in Europe and world-wide by utilizing state-of-the-art technologies through joint research projects with universities and consortia, as well as contributing European advanced technology to Hitachi's R&D network.

Germany is known as the birthplace of the automotive and as an automotive technology leader in Europe and, possibly, worldwide. The acquisition of cutting-edge technology from Europe will help Hitachi to be competitive in the global market. In this context, TEEL has established long-term collaborations with the Technical University of Munich (TUM) in the field of engine combustion technology and with Forschungsgesellschaft Kraftfahrwesen mbH Aachen (fka) in the development of chassis control technology and driver assistance systems.

Engine Combustion Technology

In order to mitigate global warming and reduce harmful emissions, regulations affecting the automotive industry will become stricter worldwide. European regulations are among the strictest. To cope with this and to provide the necessary solutions, European universities and research institutes have become leaders in the understanding of internal combustion engine technology.

Hitachi started collaborative research with TUM in 2009. TUM is one of the leading European universities in the field of engine combustion. The main objectives are the development of advanced combustion simulation technology and combustion control systems by using sophisticated measurement systems and by applying advanced design capabilities to new experimental devices.

TUM has built a single-cylinder research engine using Hitachi components, such as different types of fuel injectors, a high pressure fuel pump, and a variable valve system. The engine can run in spark ignition (SI) and homogeneous charge compression ignition (HCCI) modes, and is used to analyze the combustion process and measure emissions (see Fig. 1).

Using TUM's particulate matter (PM) sampling probe, which is capable of extracting PM directly from the combustion chamber, various PM measurements were taken and subsequently analyzed with a scanning electron microscope (SEM). The results of this work were then used in the further development of combustion simulation technology.

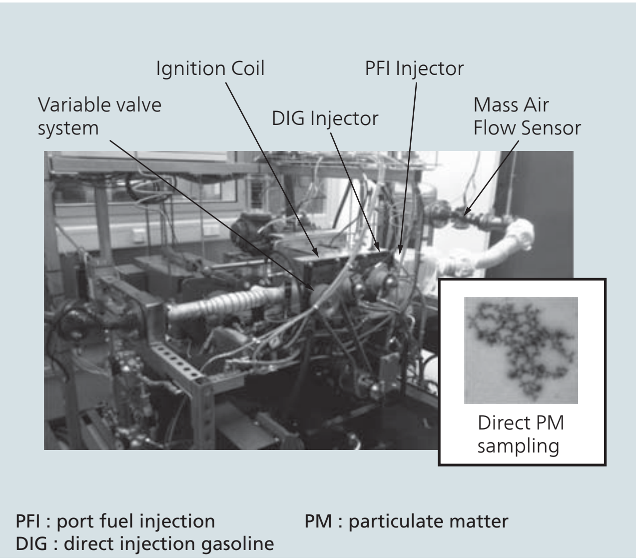


Fig. 1 | Single-cylinder Research Engine at TUM.
The engine includes Hitachi components and is used to conduct combustion analysis and emission measurements for simulation model development.

Combustion simulation technology can be used to design fuel supply components and in system control. For these purposes, Hitachi and TUM have developed three-dimensional combustion simulation technology for estimating the amount of particulate matter generation in direct-injection gasoline (DIG) engines. Analyzing the mechanism for PM generation in DIG engines requires more detailed modeling than conventional PM estimation models, which are mainly used in the simulation of diesel engine combustion. This is because the amount of PM produced by a DIG engine is considerably less than that from a diesel engine. Therefore TEEL and TUM jointly developed a detailed chemical PM reaction model (see Fig. 2). Finally, to reduce simulation costs, a framework was developed that links the detailed chemical PM reaction model to the three-dimensional combustion simulation technology. This uses a PM generation rate database derived from a detailed chemistry model.

The next steps are to develop combustion concepts with next-generation technologies led by Europe. These include a central mount injection system, high-pressure fuel supply system, and variable valve system, and are intended for achieving compliance with future CO_2 regulations around 2020.

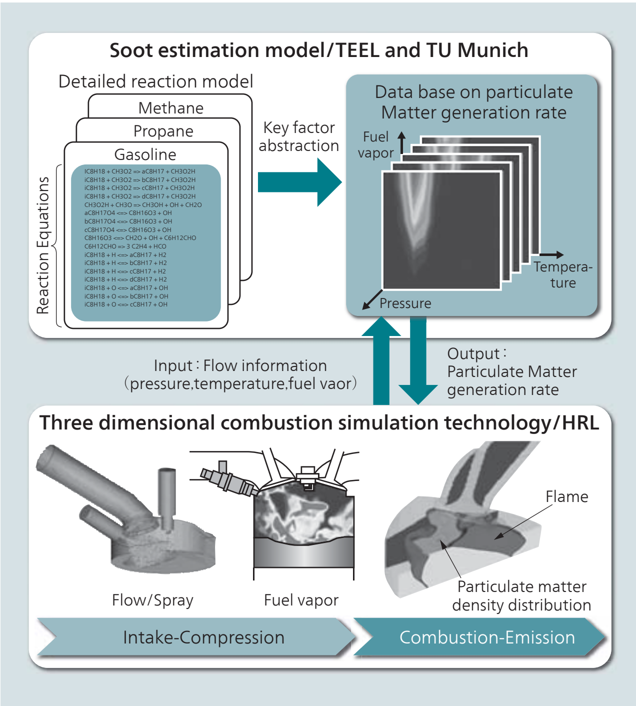
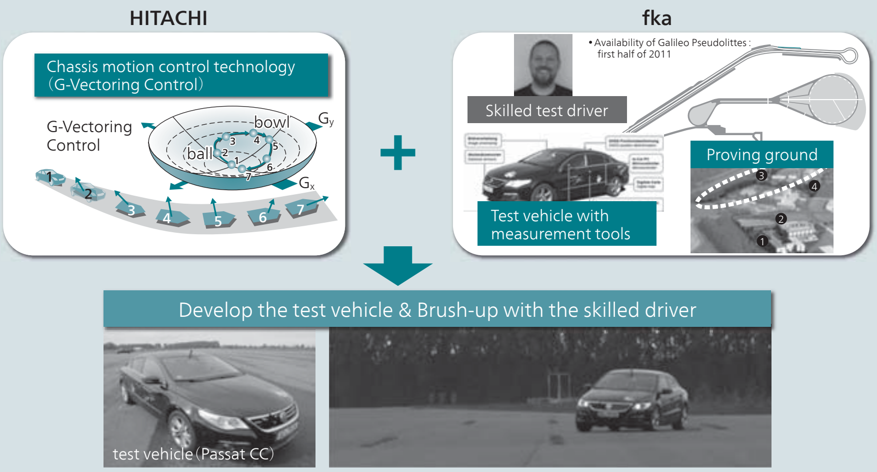


Fig. 2 | Three-dimensional Combustion Technology for Analyzing Mechanisms of Particulate Matter Generation.
TEEL and TUM have developed a detailed reaction model and a framework that links the detailed chemical model and three-dimensional combustion simulation technology.



fka : Forschungsgesellschaft Kraftfahrwesen mbH Aachen

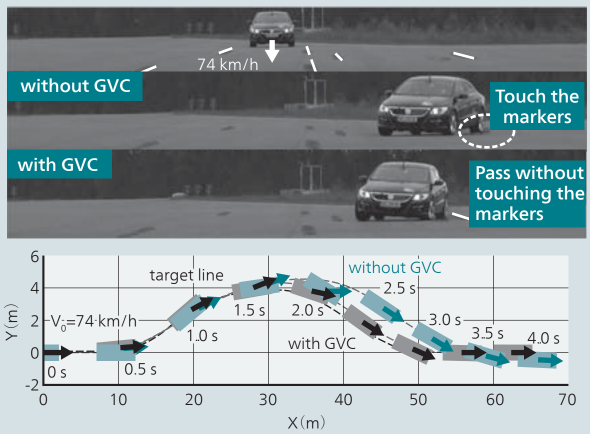
Fig. 3 | Overview of First Project (Evaluation of G-Vectoring Control in Germany).
A Volkswagen Passat CC test vehicle with G-Vectoring Control was evaluated by a skilled driver in Germany.

Chassis-motion Control Technology

To improve vehicle performance in terms of the environment, safety, and driver experience, it is important not only to improve each component, but also to develop a new chassis-motion control system that can assist the driver during routine driving. In this context, TEEL is focusing on the development of a human-inspired driver assistance system that is based on a control algorithm derived from a skilled driver. This is intended to improve driving quality, not only during routine driving, but also over a wide range of speed and weather conditions (highway speeds and conditions such as heavy rain, snow, or fog).

The first step was an evaluation of Hitachi's G-Vectoring Control (GVC)[1] chassis motion control system by fka in Germany (see Fig. 3). Founded in 1981 as a spin-off from the Institut für Kraftfahrzeuge of RWTH Aachen University (ika), fka is a leading engineering company in the field of automotive technology. In this project, Hitachi provided the GVC algorithm, which controls longitudinal acceleration in coordination with lateral motion and seamlessly changes the direction of the resulting acceleration on a "g-g" diagram, and fka provided the test vehicle (a Volkswagen Passat CC), a skilled test driver, and their proving ground.

The test driver tested the performance of GVC in cornering and obstacle avoidance (elk test) on dry-asphalt[2]. The test results indicated that use of GVC for deceleration control improved vehicle agility and helped prevent understeer during cornering and obstacle avoidance (see Fig. 4). The test driver also commented that deceleration under GVC provided more time for avoiding the markers and made vehicle control easier. These results indicate that use of GVC for deceleration control helps avoid obstacles without reducing driver comfort under German conditions.



GVC : G-Vectoring Control

Fig. 4 | Result of evaluation test in Germany.
Double lane change test called "elk test" was performed as the evaluation test of GVC. GVC could improve the obstacle avoidance performance without discomfort.

RESEARCH ACTIVITY IN NORTH AMERICA (APL)

Automotive Products Research Laboratory (APL), Hitachi America R&D's first laboratory, was opened back in 1989 in Michigan. APL is a corporate research lab and is involved in research on a wide range of products in collaboration with Hitachi Automotive Systems Americas (HIAMS) AM. APL is strategically located close to the main US automotive customers fostering a close interaction for engineering, research and direct interfacing with local customers. Its technical work covers the introduction of new concepts for electronic and mechatronic vehicle systems and the provision of 'solution-oriented' R&D. Activities include projects on embedded system development for automotive controllers; system modeling; engine research; chassis and suspension activity; materials research; noise, vibration, and harshness (NVH); and electromagnetic compatibility (EMC). The following sections consider two important research areas at APL in detail: (a) The development of virtual hardware-in-the-loop systems for greater product robustness, and (b) A computational approach to materials engineering for automotive component design.

Virtual Hardware-in-the-loop Simulation (vHILS) for Robust Automotive Product Design

The biggest challenge faced by the next generation of automotive electronic control units (ECUs) is the increasing complexity that results from the large number of interconnected ECUs and the increasing amount of software executing on them. It is not unusual for a luxury vehicle to have several dozen ECUs with several million lines of embedded software code. Ensuring the robust design of such complex systems, especially from a tier 1 supplier's perspective, requires advanced hardware and software validation methods. Products must also comply with the automotive functional safety standard (ISO26262) introduced in 2011. This is becoming a standard requirement from our automotive original equipment manufacturer (OEM) customers.

Advances in simulation technology and multi-domain simulation tools have driven the adoption of model-based development (MBD) as a mainstream development process, especially during the design phase of product development. Following the traditional 'V-cycle' development process, software development and validation proceed through a series of MBD processes, starting from a model-in-the-loop simulation (MILS), and proceeding to software-in-the-loop simulation (SILS), processor-in-the-loop simulation (PILS), and finally hardware-in-the-loop simulation (HILS).

HILS systems are usually very expensive and involve significant hardware and labor costs to operate. They are also characterized by the separation of observation and operation, which can make it difficult to correlate a problematic software behavior with its impact on the physical system. It is also difficult to reproduce error states when dealing with fault injection and failure mode and effects analysis (FMEA) for testing product reliability. In order to deal with these HILS issues, APL has been developing a virtual HILS system. As the name suggests,

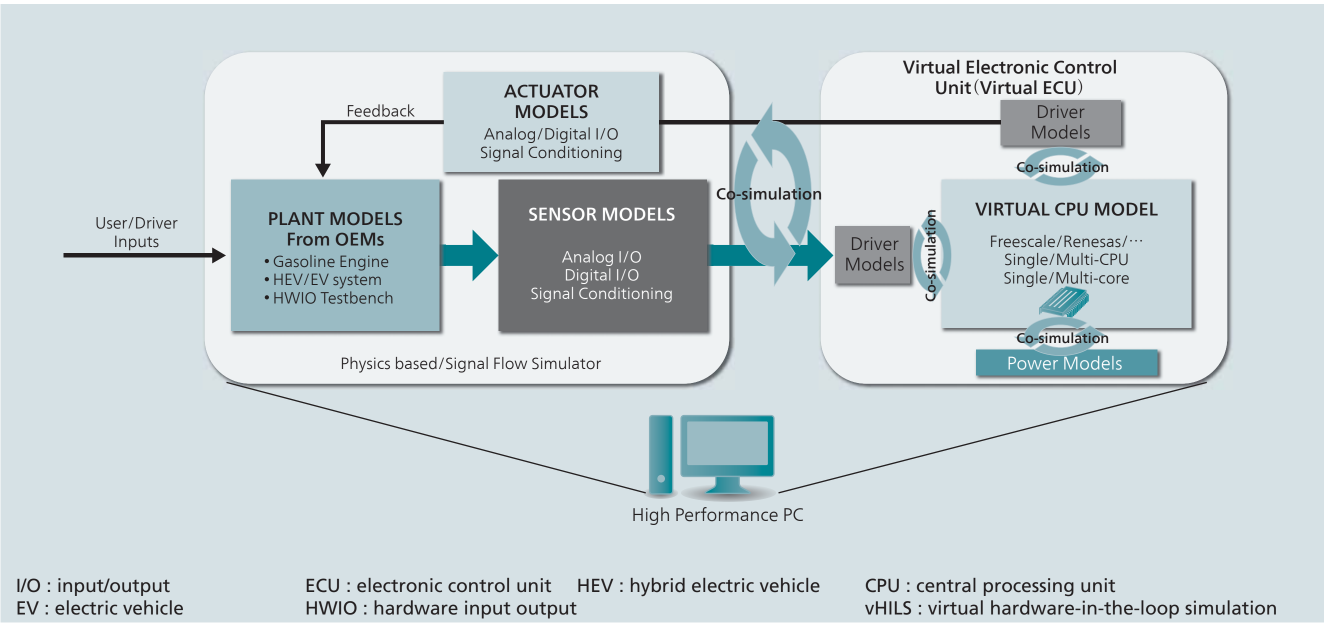


Fig. 5 | vHILS.
Workflow for vHILS implementation.

this involves implementing the complete HILS system virtually on a high-performance personal computer (PC) (see **Fig. 5**).

In comparison with HILS, which combines a real hardware ECU with a simulated physical system (plant model), vHILS uses a simulation model of the ECU itself with a low level of abstraction, including a high-fidelity model of the microcontroller that can execute the same production-grade software as the real ECU. The plant models used in the HILS system are reusable, and use co-simulation technology to interface with the ECU model. APL has proven expertise in co-simulation technology, with successful projects involving international co-simulation in which models are run across multiple research labs.

vHILS technology offers several benefits, including fully virtualized HILS, easy duplication of simulation environments, detailed target visibility (visualization of hardware and software execution), and automation. It also provides an environment for virtually testing functional safety compliance and a tool for fault injection and virtual FMEA (vFMEA). From a tier 1 supplier's standpoint, the vHILS approach can be placed within the existing controller development cycle as shown in **Fig. 6**.

When the traditional approach is used, hardware or board-level problems can go undetected during the design stage, not appearing until HILS testing in the validation phase. The OEMs may also request that changes be incorporated late in the design stage. Both of these can result in large time and development costs for hardware redesign, as indicated by the red feedback arrows in **Fig. 6**. On the other hand, the vHILS approach allows software validation to take place early in the design stage itself and potentially eliminates the time taken for hardware redesign and the associated development costs. It also provides an opportunity to provide feedback to the OEM about their specification early in the design phase. This may be necessary, for example, if an error in the specification looks like it may cause the product to function inappropriately in the system.

It is important to note, however, that this does not eliminate the need for HILS testing in the validation phase, which is typically performed by the OEM at their facility in collaboration with the tier 1 supplier. This process involves a real test of the actual product. Rather, the value of vHILS lies in its allowing early software validation and helping reduce the overall time to market by detecting hardware-related faults early. **Fig. 7** shows an example of how use of vHILS reduced the development time for an adaptive cruise control system to be supplied to a Japanese OEM.

Computational Approach to Materials in Automotive Component Development

Automotive components usually experience a complex deformation history during service. The nature of the load

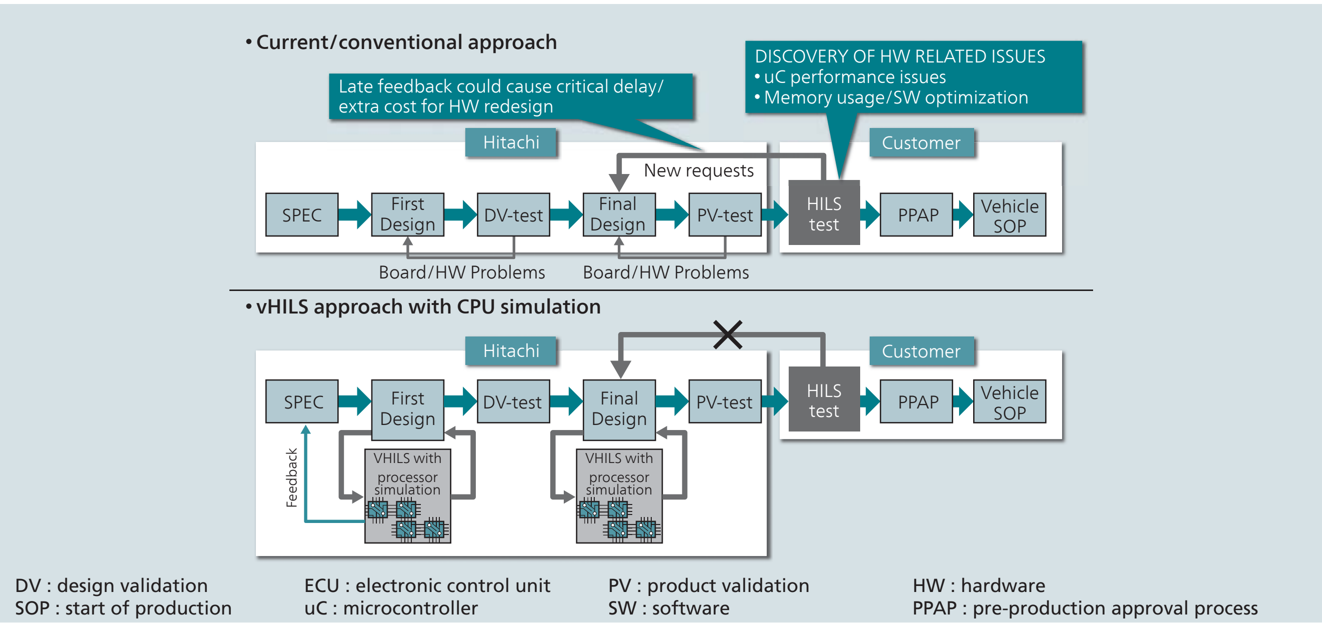


Fig. 6 | Benefits of vHILS and its Role in Controller Development Cycle.
vHILS approach ensures no delay in hardware implementation at the customer's end.

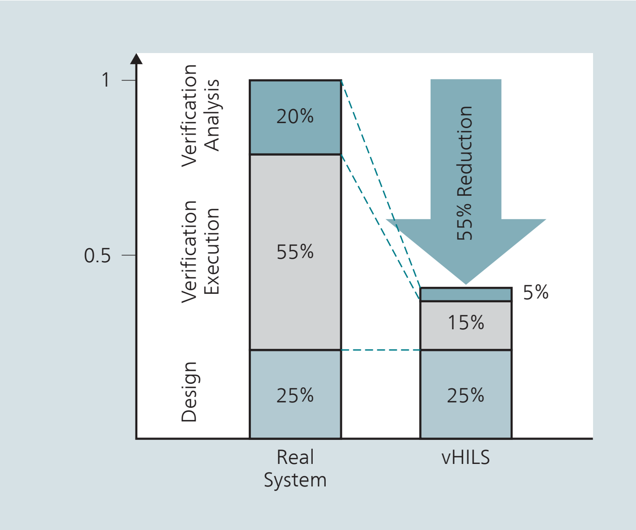


Fig. 7 | Reduction in Development Cycle Time.
Reduction in development time can translate to improved profitability.

and how the material responds are key factors in improving the design of a component for specific applications such as service life. Most materials research for new component development adopts an empirical or trial and error approach. Computational tools such as finite element methods have been widely adopted and have proved beneficial in many areas such as mechanical engineering. However, computational tools have yet to be widely used in materials engineering, not only because of the complexities of materials over different scales, from nanometer to meters, but also because there has been a lack of effort aimed at using computational tools in materials development.

APL has embarked on research into the simulation of deformation in materials or components using a combination of advanced computational tools and theoretical materials science, specifically a technique called the crystal plasticity finite element method (CPFEM). With the objective of predicting the non-uniform deformation behavior of automotive components, APL is developing a mesoscale simulation methodology that uses CPFEM to analyze component deformation under uniaxial and multi-axial loads. The two different modes of material deformation are elastic and plastic deformation, each of which has different characteristics. In CPFEM, the stress-strain gradient is assumed to arise solely from crystalline slip during plastic deformation, and from lattice stretching, rotation, and rigid body motion during elastic deformation. The plastic strain rate is thus calculated from a summation of slip rates over all slip systems, appropriately weighed by the tensor products of their respective slip directions and the normal to the slip plane. For a given slip system, the slip rate is related to the resolved shear stress by a postulated flow rule, such as the power law form in the classic Peirce-Asaro-Needleman model. The slip strength, meanwhile, is governed by a hardening equation which may depend on the slip strains in all slip systems (see **Fig. 8**).

Consider, as an example, predicting the surface shear strain distribution during uniaxial tensile loading of polycrystalline austenitic stainless steel 316 with a random crystal orientation. **Fig. 9** shows how a miniature dog bone model is constructed and further meshed. Only the gage section is modeled using CPFEM, with the Mises-Plasticity law being used for the remaining material. The

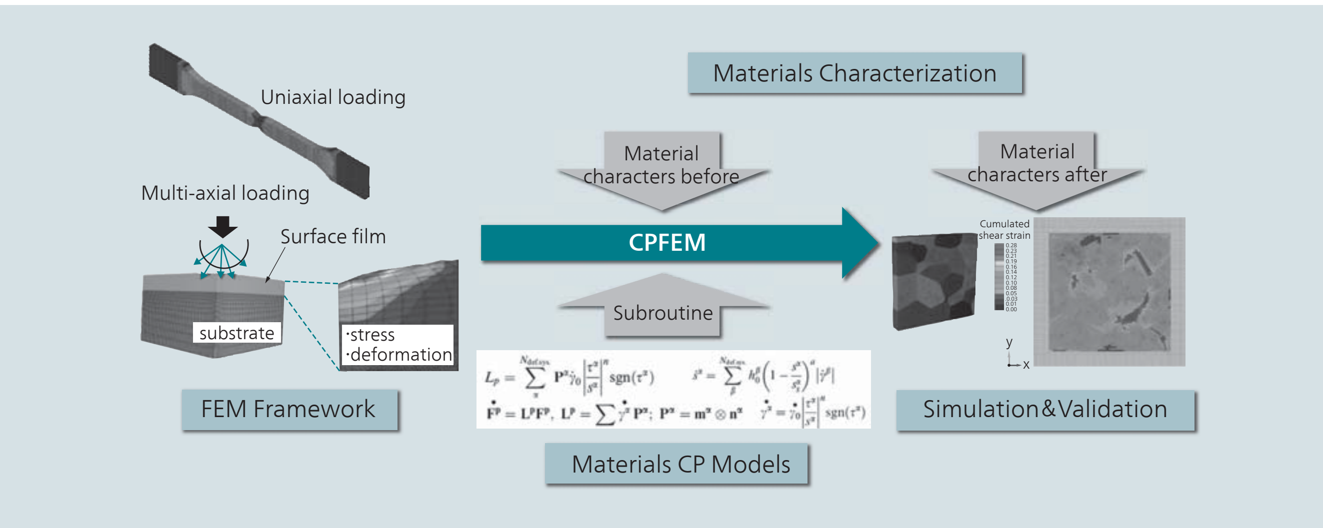


Fig. 8 | Overview of Research into Deformation Simulation Using CPFEM.
APL will implement this methodology to support future product designs.

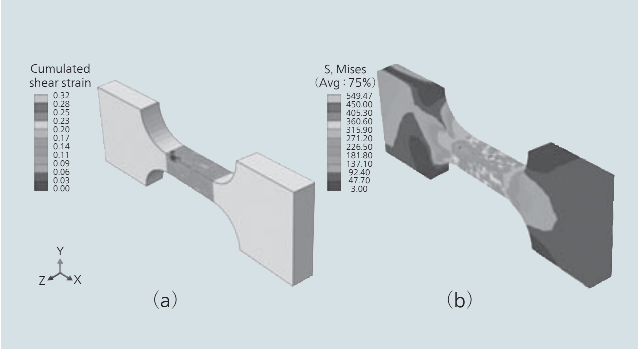


Fig. 9 | CPFEM Model for Simulating Uniaxial Tensile Testing.
The SUS316 material is assumed to have a random crystalline orientation. The results show: (a) cumulative shear strain over all slip systems in the gage section, and (b) Mises stress over the whole specimen.

gage section consists of 375 cubic grains, each of which is assigned a set of crystal plasticity parameters (the values are the same as in Ref. [(3)]) and a random crystal orientation. One end of the specimen is completely fixed, while a uniform tensile stress is applied on the other end. **Fig. 9** shows the cumulative shear strain due to crystalline slip and the Mises stress contour for a certain level of deformation.

CPFEM is seen as a powerful tool for predicting and interpreting material deformation behavior. While the above simulation assumes a random orientation and uses assumed grain shapes and sizes, it demonstrates the ability of CPFEM to be used for mesoscale simulation.

CONCLUSION

This article has described some of the advanced automotive R&D activities that are underway in Europe and the United States.

A wide range of research activities have been explained in detail, including spray pattern analysis and combustion research, chassis dynamics and control, vHILS implementation for product development, and the use of computational analysis for materials engineering. Hitachi will also have the opportunity to participate in 'global Tokken' projects which help achieve synergies between the goals and research topics at different R&D facilities within Hitachi.

One of the major benefits of having operations around the globe is that different regions can strive to become a 'center of excellence' in specific technical areas. This can benefit the company as a whole if this expertise can then be shared among different research and business groups worldwide to create a truly 'global' collaboration. In any large conglomerate, such as Hitachi, it is often the case that the same or similar type of work (in terms of research) may be carried out by different groups who may not be in communication with each other. This is an inefficient allocation of resource, time, and money, and does not add value. Instead, the ideal is to have a global collaborative effort that maximizes our available resources and minimizes redundancies, while also contributing to social innovation. This would enable Hitachi to provide cutting-edge technology to our customers while keeping a step ahead of our competitors.

feature articles

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ABOUT THE AUTHORS

George Saikalis, Ph.D.
Joined Hitachi America, Ltd. in 1990 and now works at the Research and Development Division. He is currently Vice President engaged in many aspects of automotive R&D. Dr. Saikalis is a member of IEEE and SAE.

Harsha Badarinarayan, Ph.D.
Joined Hitachi America, Ltd. in 2003 and now works at the Research and Development Division. He is currently Sr. Researcher & Group Leader engaged in automotive R&D. Dr. Badarinarayan is a member of ASME and SAE.

Yoichi Sugita, Dr. Eng.
Joined Hitachi, Ltd. the Research and Development Division in 1992. He is currently engaged in management of the Transportation, Energy and Environment Research Laboratory.