Research Assessment Exercise 2020
Impact Case Study

University: The University of Hong Kong
Unit of Assessment (UoA): 14 mechanical engineering, production engineering (incl. manufacturing & industrial engineering), textile technology and aerospace engineering

Title of case study: *High-strength steels for lightweight automobiles and lower emissions*

(1) Summary of the impact

Researchers at HKU invented a modified process for producing a quenching and partitioning (Q&P) steel for lightweight automobiles. China Baowu Steel Group has employed this new process to produce Q&P steels which have been used by 12 car makers worldwide. The application of the Q&P steels results in a reduction of about **56,000 tons of particulate matter (e.g. PM 2.5 and PM 10)**, as well as a reduction of about **472,000 tons of greenhouse gas**. The present Q&P steel has generated an income of about to the China Baowu Steel Group.

(2) Underpinning research

It is known that the automotive industry is one of the leading greenhouse gas emitters. New policies have been launched in order to reduce greenhouse gas emissions. For instance, the European policy requires that the CO_2 emission for passenger cars is reduced to 76 g/km by 2025 and 57 g/km by 2030. In China, new policies demand that the gasoline consumption for passenger cars is reduced to 4 L/100km by 2025 and 3.2 L/100km by 2030. One effective way to cut emissions is to reduce the weight of the vehicles. A reduction of 10% in a vehicle's weight can cut its fuel consumption by 6-8%. The most cost-effective way of reducing a vehicle's weight is to use Advanced High Strength Steels (AHSS). The high strength offered by AHSS leads to thinner components and therefore lighter cars. Research has therefore been carried out worldwide to develop new AHSS for automotive applications. Dr. Huang's group has been working in this area since joining HKU in 2010 and the research results have been published in top journals including *Science* and *Acta Materialia* [1-4] or patented [5].

Quenching and Partitioning (Q&P) steel is a new AHSS and was first proposed in 2003 by Prof. Speer and co-workers at Colorado School of Mines, USA. The original processes they proposed to produce Q&P steel were as follows. The Q&P steel is firstly austenitised at a high temperature (~850 ^{o}C) to achieve a full austenite phase. Following this, it is rapidly quenched to a temperature (~300 ^{o}C) higher than the martensite finish temperature, then reheated and held at a partitioning temperature (~400 ^{o}C) before it is finally quenched to room temperature. Employing the original Q&P process, China Baowu Steel Group produced the first Q&P steel in 2009. However, the industrial production line was not capable of satisfying the required cooling rate, resulting in unsatisfactory mechanical properties. In other words, the original Q&P steel is not suitable for room-temperature stamping processes due to its poor elongation (~10%). The present research [4] carried out by Dr. Huang's group and co-workers found that the slow cooling rate in real industrial production lines leads to the formation of proetutectoid ferrite as well as a non-uniform carbon distribution in the retained austenite. In particular, this research found, for the first time, that despite a much lower carbon content, low-carbon film-like austenite is more stable than high-carbon blocky austenite during deformation. Such retained austenite grains with a non-uniform carbon distribution are not mechanically stable enough to provide a good transformation-induced plasticity (TRIP) effect, leading to a rather poor work-hardening rate and elongation. Based on these findings, a modified process was

proposed to produce Q&P steel. The new process uses a two-phase region annealing at a lower temperature (~750 ^{o}C) instead of a conventional fully austenitisation annealing process at the high temperature (~850 ^{o}C). This low-temperature annealing process improves the work-hardening rate and elongation (~20%) while keeping the same ultimate tensile strength, satisfying the elongation requirement of the room-temperature stamping process.

(3) References to the research

[1] B.B. He, B. Hu, H.W. Yen, G.J. Cheng, Z.K. Wang, H.W. Luo*, **M.X. Huang***, High dislocation density induced large ductility in deformed and partitioned steels, *Science*, 1029-1032, vol357 (2017).
[2] P. Zhou, Z.Y. Liang, R.D. Liu , **M.X. Huang***, Evolution of dislocations and twins in a strong and ductile nanotwinned steel, *Acta Materialia*, 96-107, vol 111 (2016).
[3] ZY Liang, X Wang, W Huang, **M.X. Huang***, Strain rate sensitivity and evolution of dislocations and twins in a twinning-induced plasticity steel, *Acta Materialia*, 170-179, vol 88 (2015).
[4] X.C. Xiong*, B. Chen, **M.X. Huang***, J.F. Wang, L. Wang, The effect of morphology on the stability of retained austenite in a quenched and partitioned steel, *Scripta Materialia*, 321-324, vol 68 (2013).
[5] **M.X. Huang**, B.B. He, Dual-phase steel and method for the fabrication of the same, PCT patent, PCT/Cn2016/096509, pending.

(4) Details of the impact

The materials and processing costs of the Q&P steel are the same as conventional dual-phase (DP) steels. Cost-effectiveness is a very important factor for lightweight materials selection in the automotive industry. Although aluminium alloys or carbon fibres are excellent lightweight materials for weight reduction, they cannot be widely used for passenger cars due to their high costs. High-strength steels such as the present Q&P steel are the most cost-effective lightweight materials in the automotive industry. The present Q&P steel, for the first time, provides the automotive industry with a new, high-strength steel grade with a tensile strength as high as 980 MPa, but excellent elongation (~20%), suitable for the room-temperature stamping process that is used to produce car bodies. Before the application of this Q&P steel, the crash-resistance components produced by the room-temperature stamping process were in general made of DP steel with a tensile strength of 590 MPa. The application of the Q&P steel increases the strength level from 590 MPa to 980 MPa. It is noted that, for the same crash resistance, a car body component made of a higher strength steel can have a thinner thickness than that made of a lower strength steel. It is commonly accepted in the automotive industry that the replacement of 590 MPa steel grade by the present 980 MPa Q&P steel can lead to a weight reduction of the body parts of approximately 20% while keeping the same crash performance. A 20% weight reduction in the automotive industry is considered to be a huge improvement.

After the first successful application of the Q&P steel in the Chevrolet passenger car in 2015 [5.1, 5.2], many more car makers began to employ this steel for their new passenger cars, achieving great reductions in vehicle weight and greenhouse gas emissions. For instance, 11 more car makers including Volkswagen, Nissan, Peugeot Citroen, Great Wall, BYD, Chery, FAW, SAIC Motor, Guangzhou Automobile, Changan, and JAC Motors have employed the steel for their passenger cars [5.3]. The Q&P steel is not only sold in China but also in Japan and Korea. It is expected that more car makers will use the Q&P steel. This trend is confirmed

by the sales figures: sales of the Q&P steel produced by China Baowu Steel Group Co. Ltd. were tons in 2015, 2016, 2017 and 2018, respectively [5.3].

According to the calculation by Chery (one of major car makers in China) and data available in literature, for a typical passage car with a weight of 1.6 tons, a 10% of weight reduction (i.e. 0.16 ton reduction) can reduce 9.17 tons of CO_2, 0.08 ton of SO_2, 0.036 ton of NO_x and 1.1 tons of particulate matter (e.g., PM2.5 and PM 10) [5.4]. Up to August 2019, the total sales of the present Q&P steel were tons [5.3]. It is commonly accepted that the usage rate of automotive steel is about 65%. In other words, tons of the Q&P steel were transformed to automobile parts. The use of tons of Q&P steel in placement of conventional 590 MPa steel leads to **a reduction of ~472,000 tons of greenhouse gas (CO_2, SO_2, NOx) and ~56,000 tons of particulate matter** [5.3, 5.4]. For comparison, according to the data published by the Environmental Protection Department of Hong Kong Government, the total greenhouse gas emission in 2017 by the transportation sector in Hong Kong was 7,230,000 tons [5.5]. The reduction of greenhouse gas due to the use of the present Q&P steel is thus about 6.5% of the total greenhouse gas emission by Hong Kong's transportation sector in 2017. In addition to such social benefit of reduction of greenhouse gas emissions and particulate matter, the present Q&P steel also makes important economic contributions. The market price of the present Q&P steel is about HKD per ton. It indicates that the present Q&P steel has brought an income of about to the China Baowu Steel Group Co. Ltd [5.3].

Although it may be more related to academic impact, it is still interesting to mention that this research also received significant attention and citations from researchers in industry and academia. It is the top three most-cited papers published in *Scripta Materialia* since 2012 (announced in March 2018 [5.6]). *Scripta Materialia* is the second-best metallurgy journal. This is an excellent example of combining fundamental and applied research in a single project with a great impact on industry and society.

(5) Sources to corroborate the impact

5.1 News: Application of 3rd Generation Advanced High Strength Steel in GM (in Chinese), http://media.gm.com/media/cn/zh/gm/news.detail.html/content/Pages/news/cn/zh/2015/dec/1201_advanced-steel.html (last accessed on 26 Oct 2019)

5.2 News: GM applies 3rd Generation advanced high-strength steel in new vehicle for China, http://www.greencarcongress.com/2015/12/20151203-gmqnp.html (last accessed on 26 Oct. 2019)

5.3 Corroborating statement from the Head of the Automotive Steel Department, China Baowu Steel Group Co. Ltd.

5.4 Emission calculation method by CHERY

5.5 Greenhouse Gas Emissions in Hong Kong, Hong Kong Government, 2018

5.6 Citation proof of the research