Development of High Strength Steels for Energy Efficient Process Chains in Forging Industry

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Summary

While energy costs are steadily rising, energy efficiency is developing into a mega-topic in the manufacturing industry. Steel developments can contribute significantly to this. Hence, two developments concerning two different steel application families will be presented. These steels have been developed as a joined venture between Georgsmarienhütte GmbH and Hirschvogel Automotive Group.

Concerning steel for structural parts without further heat treatment after forging, there are two major trends to be recognized. One is the development of steels for energy-efficient process chains. Another trend is their contribution to lightweight design efforts, by offering high-strength mechanical properties. In this paper, a steel will be presented that can be forged at different forging temperatures and transforms into desired final part properties by controlled cooling. A thermochemical surface treatment is possible, too, so a wide variety of applications seem feasible. As steel for carburizing heat treatment, this alloy shows the potential to replace more costly alloying resources but still yielding a high hardenability.

Another steel development aims at the group of induction hardenable steels. Although the advantages of induction hardening are widely known, the combination of surface hardenability by induction heat treatment together with high core hardness and toughness reached by controlled cooling after the forging operation has only been reached with the development that will be presented in this paper. Parts made from this newly developed steel have superior properties as compared to currently available grades.

This paper will show some possible or already developed applications for the two newly developed steels.

Key Words: Bainite, H2-Steel (16MnCr5 mod.), H50-Steel (C50 mod.), Case hardening, Forging, Induction hardening, Steel Development

Introduction / Megatrends in Automotive Industry

A good cooperation between customer and supplier over the whole process chain is one key potential for optimised development and an energy and cost efficient part manufacturing.

Steel development and materials optimisation today is strongly driven by the Megatrends in Automobile and Steel Industry. These are the binding targets for CO_2 emission from passenger cars and energy saving targets in process chains given by government legislation.

The tough Global targets for CO_2 reductions in fleets of the OEM shown in **Fig. 1** lead to enormous efforts in optimization of power train and total reduction of vehicle weight to meet these goals.

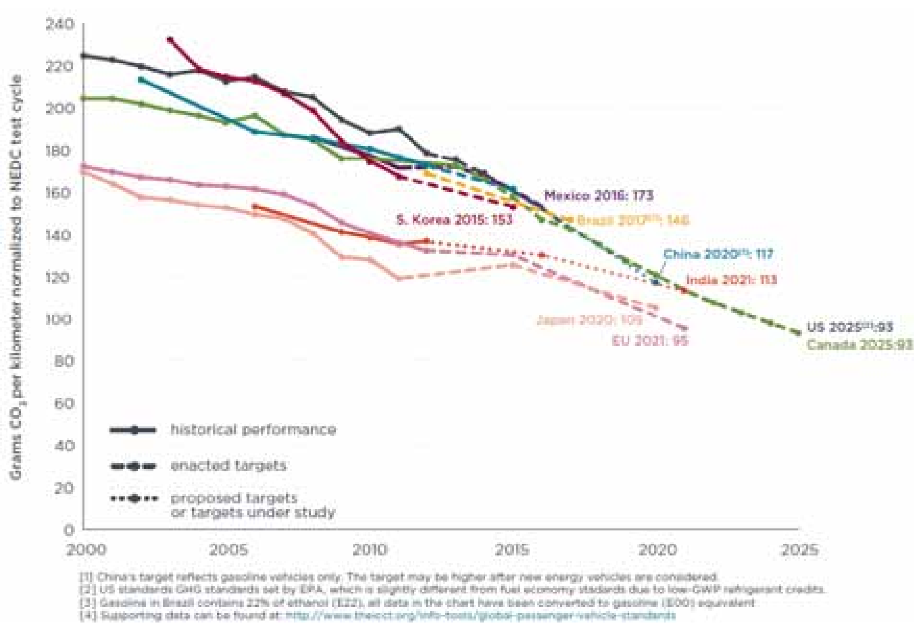

Figure 1: Historical development and future targets for CO2 emission levels of new passenger cars and light-commercial vehicles in the EU. Effects of phase-in, super-credits and eco-innovations not shown here [1]

Another fact is shown in **Fig. 2**: At present the EU is not on track to meet its 20% energy saving target by 2020.

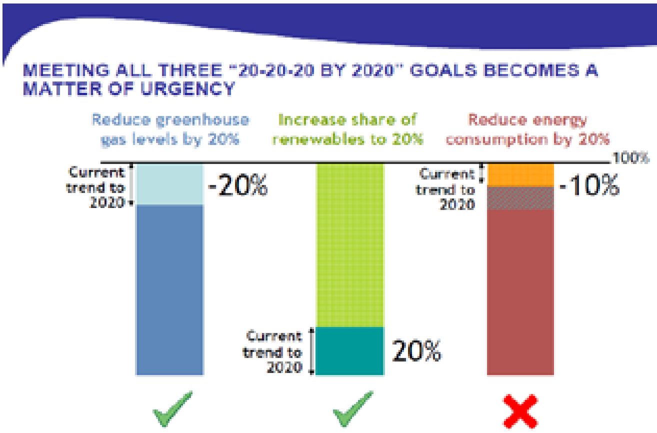

Figure 2: Current trend in meeting the 2020 energy saving targets [2]

The industry is forced to save energy and thus energy efficient process chains become very important. New developed high strength steels for forged parts can contribute significantly to these targets when taking the whole process chain into account.

Partnership in Steel Development Process

The challenges of reaching the above mentioned goals for new steel developments can only be reached by working in a team of specialists. By this all participants can contribute their experience and knowledge to reach the target efficiently. **Fig. 3** shows the process by which at Georgsmarienhütte GmbH high strength, cost efficient steel are developed.

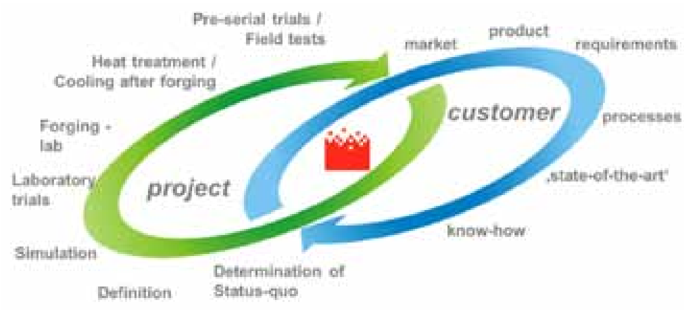

Figure 3 – Process for the development of high strength cost efficient steels

The two steel grades H2 and H50, which will be presented in this paper were developed in a joined venture together with Hirschvogel Automotive Group, according to this development process.

Tools for Steel Development Process

Thanks to successful and large research work, todays steel development work has noticeable more simulation tools for the support of pre-evaluational work than a decade ago. For example, these tools can help to defined temperatures and times for heat treatment operations. Out of the defined heat treatment, the content of retained austenite can roughly be determined. Furthermore, the calculation of the solubility of chemical elements and the simulation of phase transformations and can give a qualified idea, what behaviour a new chemical composition will show.

Although the used simulation tools deliver very trustworthy result, the next step in steel development, should always be the production of a laboratory-scale heat of the new analysis.

Application Examples

During the last years, Georgsmarienhütte GmbH together with Hirschvogel Automotive Group have developed two steels which will be presented in the following chapter. One is a micro alloyed bainitic steel which can be forged at hot or warm forging temperatures and transforms into desired final part properties by controlled air-cooling. Moreover this steel can even be used as a case hardening steel. The other steel is a medium carbon steel, suitable for warm forging and induction hardening.

Bainite for Structural Steels (H2, 16MnCr5mod.)

As already mentioned, the optimization of production processes and decrease of energy consumption is of more and more importance in modern industrial countries.

It is therefore obvious to search for technical solutions which combine the advantages of different alloying and heat treatment systems. Precipitation hardening steels show their mechanical properties directly after a defined cooling from forging temperature. A following heat treatment is not necessary. Additionally in most cases a straightening operation and a final crack testing are not necessary. However precipitation hardening steels show lower yield strength and notch impact energy in comparison to quenching and tempering steels.

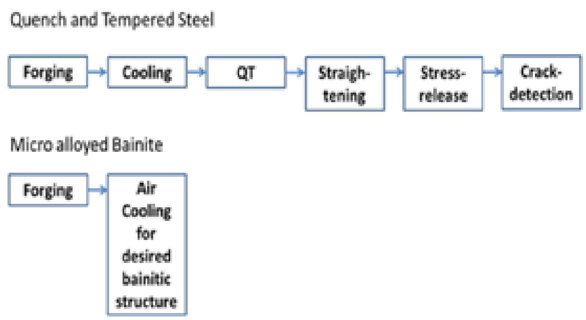

Figure 4 – Advantages in the production process of a micro-alloyed bainitic steel compared to a quench and temper steel

The newly developed micro-alloyed 16MnCr5 mod (H2 – Hirschvogel melt no 2) uses this potential. It combines the advantages of precipitation hardening steel and quenching and tempering steels. Precipitation hardening steels will. Thus results in short production times and good mechanical properties. See **Fig. 4** and **Tab. 1**.

A further advantage of the H2 steel is its cost-efficient alloy design without molybdenum as an alloying element. Together with the savings in heat treatment, the H2 allows for the development of higher-strength parts in comparison to dispersion-hardening steels, or Q+T-steels. By this, these steels can be replaced with a more cost- and energy-efficient solution. An example is shown in **Fig. 5**. Here the costs for the steel and its heat treatment, the forging and the turning operation are compared for the H2 steel and two typical quench and temper steels.

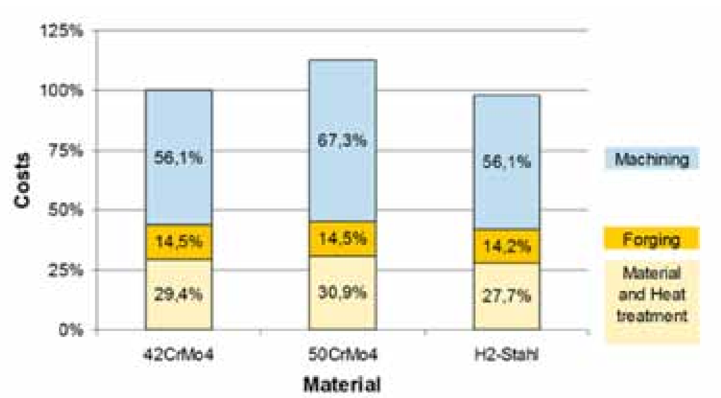

Figure 5 – Summary of different cost types for the production of injector parts [3], [4]

The data in **Tab. 1** show a comparison of the mechanical properties of an injector body which is used in today's common rail diesel injection systems. They were produced from three different kinds of steel by warm forging. It is obvious that the air hardenable H2 steel shows similar mechanical properties as a quench and tempered 42CrMo4. This applies to yield strength as well as notch impact energy.

Part		Material	R_m / MPa	$R_{p0,2}$ / MPa	A / %	Z / %	Av / J
Injectorbody		42CrMo4	940	850	15	57	95
		50CrMo4	1170	1070	12	45	52
		H2	1050	800	16	65	115

Table 1 – Mechanical properties of warm forged injector bodies [4]

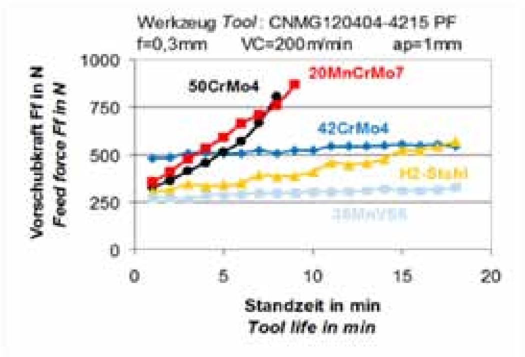

Figure 6 – Results from H2 turning tests at ISF in Dortmund [4]

Looking at the value for yield strength and notch impact energy of the H2 steel, the turnability of H2 might be taken into consideration. Moreover the sulphur-content of the evaluated H2 heat was only 0,012 wt.%.

Together with the ISF in Dortmund the machining properties were analysed. These analyses, which were presented in **Fig. 6**, yielded promising results.

Figure 7 – Examples for parts made of H2 steel. Hot forged Rail for a Diesel injection system (left) and a cold forged transmission-shaft (right) (source Hirschvogel Automotive Group)

Steel for Case Hardening (H2-Steel, 16MnCr5mod.)

As a steel grade, suitable for carburizing heat treatment, the H2 steel grade shows high hardenability as shown in **Tab. 2**.

Steel	Variation	J1,5	J5	J11	J20
20MnCrS5 +HH	Min.	41	36	28	23
	Max.	49	48	42	37
16MnCr5mod (H2)	Min.	42	42	41	38
	Max.	48	48	47	45
18CrNiMo7-6 +H	Min.	40	39	36	32
	Max.	48	46	44	41

Table 2 – Hardenability of H2 steel in comparison with 18CrNiMo7-6 and 20MnCr5 (source Hirschvogel Automotive Group)

This property is reached although using a cost-efficient alloy design without molybdenum as an alloying element. This alloy shows the potential to replace more costly alloying resources but still yielding a high hardenability. This shows the perspective towards high strength parts at attractive cost levels.

This perspective towards high strength parts at attractive cost levels is even more supported, when comparing the results of H2 and 18CrNiMo7-6, **Fig. 8** and **Fig. 9**.

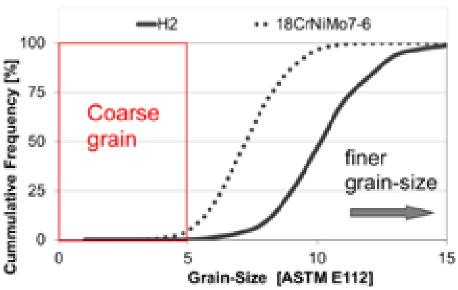

Figure 8 – Grain size distribution after case hardening at 1000°C

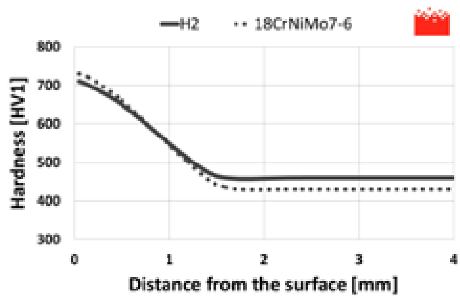

Figure 9 – Carbon-distribution after case-hardening

Steel for Warm Forging and Induction Hardening (H50, C50 mod.)

Another promising approach for the optimization of production processes and decrease of energy consumption is the use of medium carbon steels for warm forging in combination with induction hardening

One of the advantages of induction hardening is the little space such equipment requires. Thus it is possible to implement induction hardening in line to make a single-piece-flow possible. Less investment and reduced heat of first running are additional advantages. To use the advantages of the combination of warm forging and induction hardening in an optimized way, a new steel grade called H50 steel was developed. After Forging and controlled cooling, the H50 steel shows high core hardness and a microstructure consisting of pearlite and approximately 5 % ferrite. Detailed informations about the mechanical properties of H50 steel are to be found in **Tab. 3**. Additionally a measured grain size of 7 to 9 on the flange shaft should be mentioned.

Part: Flanged Shaft	Material	R_m / MPa	$R_{p0,2}$ / MPa	A / %	Z / %	Av / J
	H50	930	550	13	60	13

Table 3 – Mechanical properties of warm forged H50 parts (source Hirschvogel Automotive Group)

Figure 11 – Examples for parts made of H50 steel. Wheel hub (left) and Rezeppa with forged face gear (right) (source Hirschvogel Automotive Group)

Conclusion

By means of joined ventures between steel manufacturers and steel users it is possible to find solutions for the challenges of todays and future steel applications for the OEM. The development and optimization of steel grades offers the opportunity for customers in their production processes to save energy and time. However, it was shown, that these goals can be reached without losing superior mechanical properties.

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