Technological Properties of the New High Strength Bainitic Steel 20MnCrMo7

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Summary

The new steel 20MnCrMo7 was developed to obtain a fine grained bainitic microstructure on cooling in air from hot rolling or forging temperatures with a high tensile strength of about 1250 MPa required to meet the future demands for high pressure components in automotive applications.
The application for hot forged common rails for diesel engines from this steel grade has been reported in the past. This paper presents further technological properties of this steel indicating its suitability for different automotive applications.
The technological properties reported are:

i) **Hardenability:** The steel 20MnCrMo7 has a Jominy hardenability, which is superior to that of nickel alloyed steels such as 18CrNiMo7-6, indicating the possibility of substituting the more expensive Nickel containing steel grade for gear applications.

ii) **Fine grain microstructure**: A fine grained microstructure is obtainable up to temperatures of 1050 °C. This fine grain behaviour enables case hardening of components at higher temperatures.

iii) **Case hardening treatment:** High case hardness in connection with a high core hardness makes this steel attractive for high stressed, case hardened components such as nozzle bodies in common rail diesel engines.

iv) **Cold forming:** In the AC-annealed state this steel shows a relatively moderate strain hardening rate making it suitable for cold forming processes. An example of a cold formed high pressure connection bolt for common rail diesel engines is reported.

These aspects indicate the potential of the steel 20MnCrMo7 making it technically and commercially an interesting alternative to Nickel alloyed engineering steels such as 18CrNi8 and 18CrNiMo7-6.

Key Words:
Bainitic steel 20MnCrMo7, hardenability, fine grain microstructure, tensile strength, impact toughness, case hardening treatment, cold forming.

1. Introduction

For many applications in the future new steel grades are required with a good combination of high strength (above 1150 MPa) and adequate ductility. These properties can be obtained from alloyed quenched and tempered steels. However for automotive applications the combination of high strength and ductility should ideally be obtained without any quenching and tempering treatment.

Since 1972 the microalloyed ferritic-pearlitic steels for precipitation hardening have been developed in Europe. These steel grades can obtain tensile strengths of up to 1000 MPa with moderate ductility and are being applied for automotive components such as crankshafts, steering knuckles and conrods. These steel grades have been standardized in the European standard EN 10267 [1].
The microalloyed ferritic-pearlitic steel grades are also being used in common rail diesel engines for pressures up to 2400 bar. A further increment in the pressure of these diesel engines is however necessary for them to become more efficient, more economical and to meet more stringent environmental standards. For steel components such as injectors, the present tensile strength of about 1000 to 1050 MPa will not be sufficient for application at pressures above 2400 bar. Thus development work has to be done to find new steel grades with higher tensile strengths (above 1150 MPa) and which ideally do not require any quenching and tempering treatment subsequent to hot rolling or hot forging and still obtain a good combination of strength and ductility.
One possibility of increasing the tensile strength is to design chemical compositions leading to a bainitic /martensitic microstructure, which has a higher strength than the ferritic-pearlitic microstructure. If the bainitic /martensitic microstructure is fine grained, then the possibility of obtaining a suitable combination of high strengths above 1150 MPa with adequate ductility is given.

The result of one such development study has led to the new steel grade 20MnCrMo7. Another project to use this steel grade for rails of common rail diesel engines has also shown positive results. These results were presented in the SCT Symposium in 2008 [2].
In this paper further technological properties of this steel grade are presented, illustrating the possibilities of using this steel grade for other interesting applications in the automotive industry.

2. Steel Design

The steel 20MnCrMo7 was designed to be able to obtain a robust lower bainite microstructure on cooling from hot rolling or hot forging temperatures. This bainitic microstructure can be achieved basically with a combination of Manganese and Chromium with small additions of Molybdenum. To obtain a fine grain structure a suitable combination of Niobium, Titanium and Nitrogen is additionally added.
In order to make the steel weldable, the Carbon content is restricted to 0.20%.
An industrial heat with a weight of 120 tons has been melted with the following nominal chemical composition:

C	S	Mn	Cr	Mo	Ti	Nb	N	
~0.205	~0.011%	~1.60%	~1.6%	~0.20%	+	+	+	

Table 1: Nominal chemical composition of 20MnCrMo7

The Sulphur content is kept at about 0.01% for machinability purposes. Higher Sulphur contents could be detrimental for the fatigue properties of high strength steels.

3. Investigation procedure

The aim of determining the technological properties mentioned below is mainly to find out the possible use of this steel for further applications. It is of utmost interest to find out whether this steel grade can replace Nickel containing steel grades, which are not only more costly but also have the additional disadvantage of the price of Nickel alloys being very volatile.

- **Hardenability:** The hardenability is determined in the Jominy test. This test is standardized in the EN ISO 642 [3]. The hardenability values are compared with those of the case hardening steel grade 18CrNiMo7-6+HH [4] in order to find out whether the steel 20MnCrMo7 is in a position to replace Nickel containing steel grades for automotive gear applications such as cog wheels or gear pinions.
- **Fine grain microstructure:** The grain size behaviour is determined in accordance with the ASTM E 112 specification [5], which is basically similar to the EN ISO 643 standard [6]. The samples are taken from a hot rolled wire rod with a diameter of 21 mm and heated at temperatures of 900 to 1050°C for holding times of up to 20 hours.
- **Case hardening behaviour:** Initial results of the surface and core hardness of this steel grade obtained after a case hardening treatment are presented. The behaviour after case hardening gives an indication of whether this steel grade is suitable for applications such as nozzle bodies of diesel common rail injectors, which today are made from the steel grade 18CrNi8.
- **Cold forming:** Many automotive parts are manufactured by cold forming operations. It is therefore of interest to know whether a steel with bainitic structure can be cold formed after an adequate spherodizing annealing treatment. The strain hardening rate of the steel is evaluated and an industrial trial to cold form high pressure connection bolts of the common rail diesel injectors carried out.

4. Hardenability

The hardenability of the steel grade 20MnCrMo7 is shown in Figure1. For comparison the upper level of the HH-hardenability range of the higher alloyed steel grade 18CrNiMo7-6+HH [4] is also included in the diagram.

The data shows that the grade 20MnCrMo7 has a similar hardenability as the steel 18CrNiMo7-6+HH up to a distance of 15 mm from the quenched end of the Jominy sample. At distances above 15 mm the hardenability of the steel 20MnCrMo7 is higher than that of the more costly steel grade 18CrNiMo7-6+HH. This means, that at larger bar diameters the hardenability of the steel 20MnCrMo7 is higher than that of the steel 17CrNiMo7-6+HH. This result indicates the possibility of replacing the higher alloyed steel 18CrNiMo7-6 by the new steel 20MnCrMo7. Due to these results further investigations are planned to test gear components, which today are manufactured from the steel 18CrNiMo7-6.

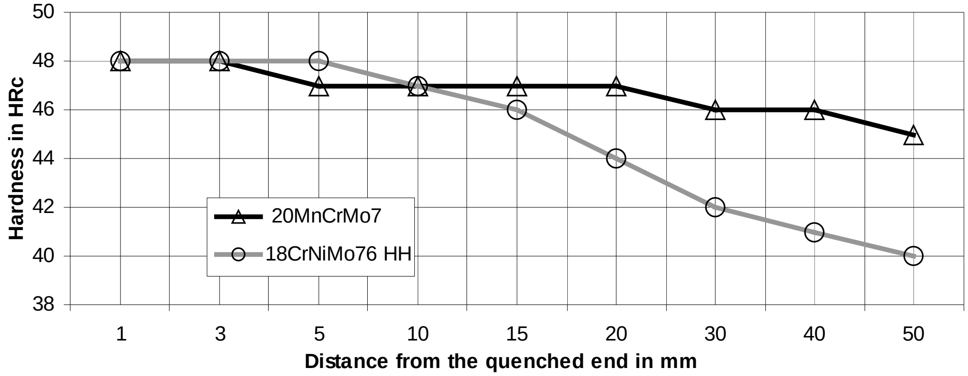

Figure 1: Hardenability of the steel 20MnCrMo7 in comparison to the steel 18CrNiMo7-6 HH

5. Fine grain microstructure

The grain size behaviour of the steel 20MnCrMo7 is determined on samples taken from 21 mm hot rolled wire rod. The typical mechanical properties determined on samples taken from the 21 mm hot rolled wire rod without any subsequent heat treatment are given in Table 2.

Tensile Strength, Rm	0.2% Proof Strength, Rp0,2	Elongation, A	Reduction of Area, Z	Impact Toughness, (DVM-Notch)
1262 MPa	856 MPa	18%	62%	40 Joule

Table 2: Mechanical properties of hot rolled wire rod of 21 mm diameter

These values emphasize the good combination of strength and ductility obtainable from a fine grain bainitic structure. An example of the bainitic microstructure of the hot rolled wire rod of 21 mm diameter is shown in Figure 2. The grain size in the hot rolled condition is finer than 8 according to the ASTM E 112 / EN ISO 643 standard.

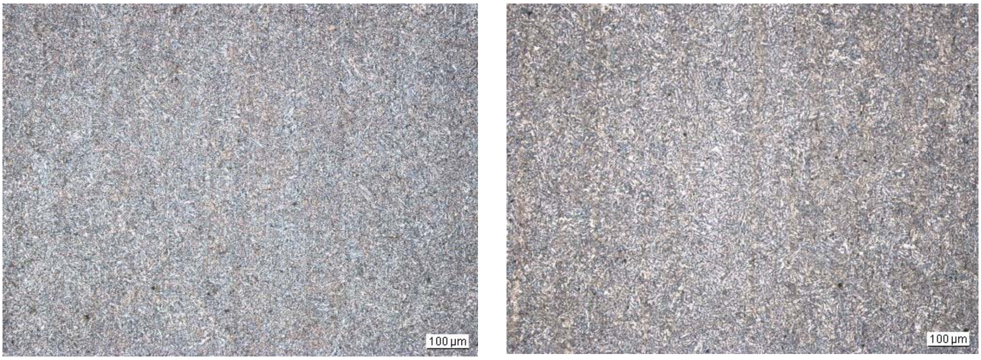

Figure 2: Microstructure of the hot rolled wire rod of 21 mm diameter (Magnification: 100:1)
(left side: surface cross-section; right side: core area)

The fine grain behaviour of this steel grade is illustrated after heating samples at 950°C, 1000°C and 1050°C for holding times between 5 and 20 hours (Table 3).

The results confirm the fine grain stability of the steel 20MnCrMo7 up to temperatures of 1050°C and holding times up to 20 hours

Temperature	Holding time		
	5 hours	10 hours	20 hours
950°C	ASTM 8 to 9	ASTM 8	ASTM 8
1000°C	ASTM 8	ASTM 8	ASTM 8
1050°C	ASTM 8	ASTM 7 to 8	ASTM 7

Table 3: Grain size behaviour of steel 20MnCrMo7.

It is to be noted that the initial state for this examination is a 21mm wire rod. If such experiments are carried out on samples from much larger sections, then deviations from these results could be expected depending on the initial dimension and the processing parameters.

6. Case hardening behaviour

The result of an initial study of the case hardening behaviour of the steel 20MnCrMo7 after case hardening and tempering at temperatures of 180°C, 250°C and 300°C is shown in Table 4.

Case hardened + tempered	Surface Hardness (0.15 mm below the surface) in HV0.5	Case Hardening Depth (at 550 HV) in mm	Core Hardness in HV10
180°C	730 to 760	0.60 to 0.65	465
250°C	690 to 730	0.52 to 0.55	460
300°C	660 to 700	0.44 to 0.49	458

Table 4: Case hardening behaviour of 20MnCrMo7

These results are of a preliminary nature as the case hardening parameters for 20MnCrMo7 are still to be optimised. A relatively high surface hardness is obtained, even on tempering the case hardened samples at 300°C. Depending on the tempering temperature the case hardening depth for a hardness value of 550HV lies at a depth of 0.44 to 0.65 mm below the surface of the case hardened sample. The core hardness remains basically the same indicating the high resistance of this steel to tempering temperatures up to 300°C.
The remaining austenite content determined lies between 10 to 20%. An optimisation of the case hardening parameters would lead to lower remaining austenite contents.
This initial study clearly shows that these characteristic values of the steel 20MnCrMo7 are higher than those values specified for nozzle bodies in diesel injectors manufactured from the steel grade 18CrNi8 [7]. These results make it evident, that the steel 20MnCrMo7 could replace the steel 18CrNi8 as the material for nozzle bodies in diesel injectors, which due to it’s Nickel content is more costly than the steel 20MnCrMo7.

7. Cold forming characteristics

The microstructure in the spherodized annealed condition and the strain hardening behaviour are two relevant characteristics in defining the cold forming properties of a steel grade. A suitable microstructure for cold forming is typically one with a high degree of spherodized carbides after the spherodized annealing treatment. The microstructure obtained in the bainitic steel 20MnCrMo7 is shown in Figure 3.

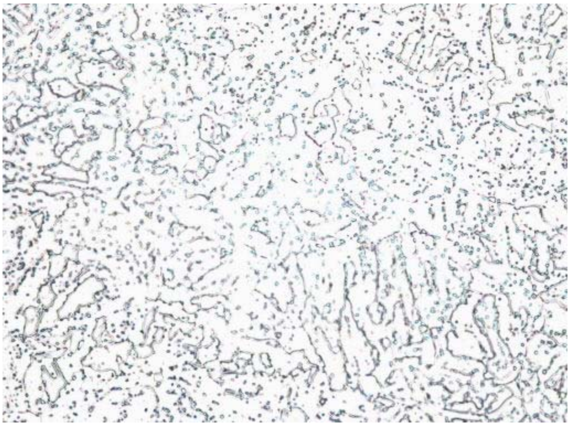

Figure 3: Spherodized annealed microstructure of the steel 20MnCrMo7 (magnification: 1000:1)

Over 90% of the carbides have coagulated as should be the case after a suitable spherodized annealing treatment.
The strain hardening behaviour of this steel grade was determined by reducing the cross-section of the annealed wire rod by a cold drawing operation. After each reduction step, the tensile strength (Rm), the 0.2% proof stress (Rp0.2), the elongation (A) and the reduction of area (Z) were determined in a tensile strength test (Figure 4).

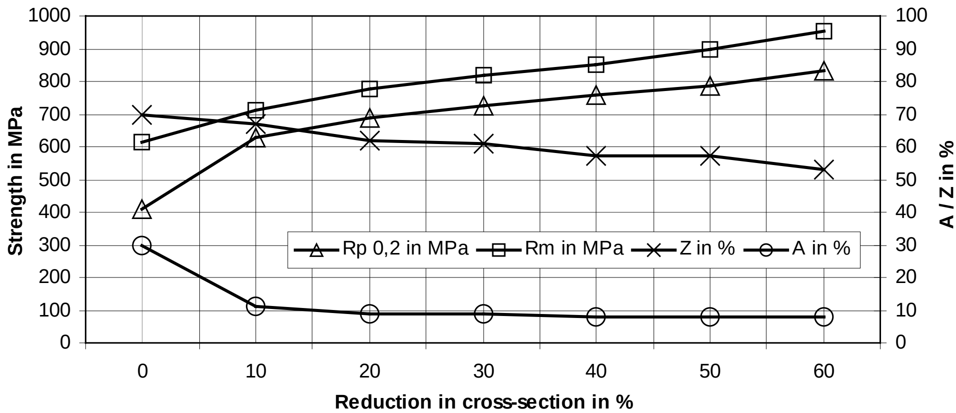

Figure: 4 Strain hardening behaviour (Rm; Rp0.2) of the steel 20 MnCrMo7

The Rm and Rp0.2 values increase relatively moderately with increasing reduction of the cross-section, indicating a low strain hardening rate of this steel grade as needed for precision cold forming processes and parts. After a cross-section reduction of 50%, the tensile strength lies at about 900 MPa and the 0.2% proof stress at 780 MPa.
The reduction of area (Z) decreases from 70% in the spherodized annealed condition to about 57% after a 50% cross-section reduction. The elongation (A) lies at about 30% in the annealed condition and then reduces to about 8% after a 50% reduction in the cross section.

The good cold forming characteristics were confirmed in a practical industrial test on cold forming the material to a high pressure connection bolt of a common rail diesel engine. The high pressure connection bolt is attached to the injector (Figure 5) and

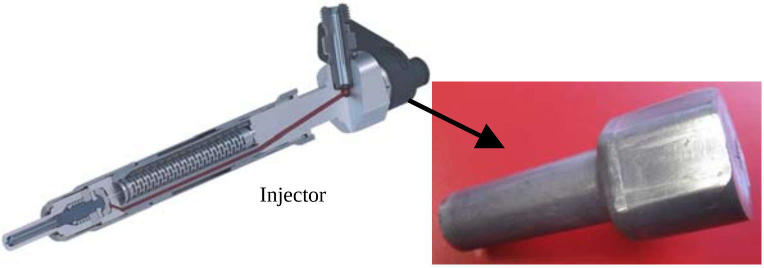

Figure 5: Injector with the high pressure connection bolt

connects the high pressure tube from the rail to the injector. The cold formed part is subsequently machined to the final configuration. About 250 parts were cold formed without any problems. The hardness values required on the high pressure connection bolt were obtained after cold forming without the necessity of a subsequent heat treatment operation.

8. Conclusions

The conclusions derived from this investigation are:

- High strength bainitic steels with 0.20%C can be designed to offer high tensile strengths of about 1250 MPa and high ductility resulting from a fine grain microstructure. The good combination of strength and ductility can already be obtained on cooling from the hot rolling or hot forging operations without a subsequent heat treatment.
- The hardenability of the steel grade 20MnCrMo7 is equivalent to and at larger bar diameters higher than that of the case hardening steel 18CrNiMo7-6+HH, indicating the possibility of replacing a more expensive Nickel containing steel grade.
- Although the case hardening behaviour of the steel 20MnCrMo7 has not yet been optimised, the initial results demonstrate the high case hardening hardness on the surface and the relatively good case hardening depth at 550 HV in connection with a high core hardness at tempering temperatures up to 300°C. The steel grade 20MnCrMo7 is an attractive alternative to the steel grade 18CrNi8 for applications such as nozzle bodies from the point of view of the cost and technological properties.

An important aspect for the application of such a bainitic steel grade for components in the automotive industry is the machinability at high tensile strength values. Recent investigations indicate the possibility of improving the machinability of these high strength bainitic steels by modifying the tool geometry and by selecting suitable tool grades [8]. Further research work is being perpetuated to optimise the machining behaviour of these high strength bainitic steel grades.

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10. References

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