

Manufacturing of complex high strength components out of high nitrogen steels at industrial level

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Abstract: High performance components, e.g., fasteners, nowadays are usually made out of cold forged and heat treated steels like steel 1.5525 (20MnB4). To overcome the problems of heat treatment, e.g., low surface quality, new workpiece materials for cold forging should be found to achieve the needlessness of heat treatment after cold forging. One possible material is given by high nitrogen steels like steel 1.3815 (X8CrMnN19-19). Due to the high strain hardening of these materials the process and tool design for an industrial batch process are challenging and should be conducted by FE-simulation. The numerical results show that, high strength tool materials, like PM-steels or cemented carbides, in most cases, are inevitable. Additionally to the selection of suitable tool materials, the tool layout should be developed further to achieve a high loadability of the tools. The FE-models, used for process and tool design, are validated with respect to the materials' flow and occurring forming force to assure a proper design process. Also the comparison of strength of components made out of steel 1.5525 in quenched and tempered conditions and steel 1.3815 in strain hardened condition is done. The results show that the component made of steel 1.3815 has a significantly higher strength than the component made of steel 1.5525. This shows that by the use of high nitrogen steels a high performance component can be manufactured by cold forging.

Key words: high nitrogen steel; heat treatable steel; cold forging; FE-simulation; Martens hardness

1 Introduction

Triggered by the discussion on carbon dioxide (CO₂) emission of vehicles the efforts for light-weight construction are increased by the automotive industry. However, usually the application of mass optimized components leads to high component loads [1]. Hence, these components, e.g., screws, should be made out of high strength materials like heat treatable steels, e.g. steel 1.5525 (20MnB4). Such steels are suitable for cold forging operations, which is advantageous due to the fact that by cold forging high accuracy is achievable and for huge lot sizes it is economically efficient. But after cold forging a following heat treatment of the components should be conducted, which is disadvantageous due to the geometrical distortion and the low surface quality. Additionally, more than ever further demands, e.g., excellent corrosion resistance or high toughness, should be met by the high performance components. Thus, heat treatable steels should be replaced by new high strength

materials which fulfill the demands listed before.

A class of steels, which satisfies those requirements, are high nitrogen steels. In these kinds of steels, carbon is nearly completely substituted by nitrogen and the nitrogen content is above 0.5% (mass fraction). The most outstanding properties of these materials are the high work hardening combined with high ductility and excellent corrosion resistance. Steels 1.3815 (X8CrMnN19-19) and 1.4452 (X13CrMnMoN18-14-3) are classical high nitrogen steels. These two steels are usually used for producing retaining rings for steam driven turbo generators. Retaining rings are necessary to keep the generators' windings at their place when the generator rotates. Usually, generators' shaft with a diameter of 2 m rotates at 3000 or 3600 min⁻¹ and power frequencies of 50 and 60 Hz. This high mechanical load, combined with the high thermal load occurring at a turbo generator leads to a high load of which the retaining rings' material should withstand. Because components made out of high nitrogen steels are able to, they represent an interesting alternative to heat treatable steels.

2 Manufacturing of high performance parts out of high nitrogen steels

2.1 Material and investigations

High nitrogen steels are used widely for manufacturing of retaining rings for turbo generators at power plants because of their excellent corrosion and cracking corrosion resistance additionally to the high work hardening.

According to Table 1, the austenitic stainless steel 1.3815 shows a nitrogen (N) content of 0.77% (mass fraction) and nearly no carbon (C). Also the contents of manganese (Mn) and chromium (Cr) are on an elevated level. The high chromium content is advantageous with respect to the corrosion resistance and the solubility of nitrogen. A high content of manganese also increases the solubility [2]. On the other hand, a low content of carbon, silicon (Si) and nickel (Ni) is advantageous to the solubility of nitrogen in the melt [3]. Another possibility to increase the solubility of nitrogen is to raise the pressure of the atmosphere during melting of steel and to create a pure nitrogen atmosphere. In the pressure-electro-slag-refining (PESR) process these two demands can be fulfilled. During the melting process an electrode is molten under the layer of slag that is built up of special salts. Due to the higher density the molten material drops through the slag layer and solidifies at the water cooled chill mould, which is made of copper (Cu). During the PESR process the pressure of the nitrogen atmosphere inside the furnace can be increased up to 4.2 MPa. During the melting process the composition of the melt can be adjusted by feeding alloying elements through the locks installed at the furnace. The nitrogen content is adjusted by adding silicon nitride (Si_3N_4) to the melt [4].

Table 1 Chemical composition of high nitrogen steel 1.3815 (mass fraction, %)

C	Si	Mn	Ni	N	Mo	Cr
0.07	0.80	18.6	0.32	0.77	0.06	18.1

Source: Energietechnik Essen GmbH.

The mechanical properties of the two high nitrogen steels 1.3815 and 1.4452 are characterized in upsetting tests. For these tests the specimens with a diameter of 8 mm and height of 12 mm are used. The test setup is shown in Fig. 1. Here, additionally an optical strain measurement system is shown.

The true strain is calculated by using the deflection corrected stroke of the test machine and the optical strain measurement system ARAMIS. For using this system, a stochastic pattern with high contrast should be applied to the specimen. For example, the needed high contrast can

be reached by using a black colour for the pattern on a white grounding. The two different evaluation methods show no significant differences in the results. However, the stroke based evaluation shows slightly higher values of about 25 MPa for the true stress σ at $0.6 \leq \epsilon \leq 0.8$. The resulting true stress—true strain curve is important for FE-based tool design because this curve is one of the most important input data. For the FE-simulations the stroke based evaluated curves are used. Hence, the tool loads calculated tend to be overestimated. This is advantageous because the tool will be designed for more load than really occurring.

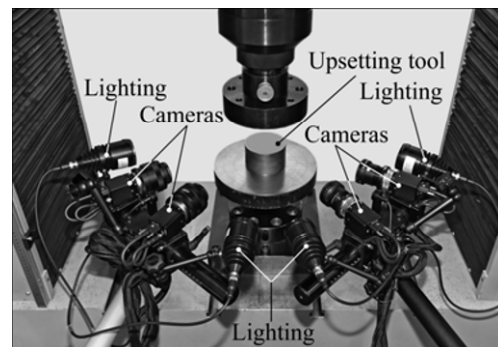


Fig. 1 Test setup of upsetting tests for determining true strain—true stress curves of high nitrogen steels

The upsetting tests are carried out at room temperature because cold forging is in the focus of the work. In order to avoid an improper temperature rise of the specimen and due to the fact that within cold forging the true strain is independent of the forming velocity, the experiment velocity is set to 5 mm/min. Otherwise, an excessive rise of the temperature will lead to an incorrect determination of the true stress—true strain curve. The results of the upsetting tests are shown in Fig. 2. It can be seen from Fig. 2 that at a true strain of $\epsilon \approx 0.75$ a difference of stress $\Delta\sigma \approx 204$ MPa between steels 1.3815

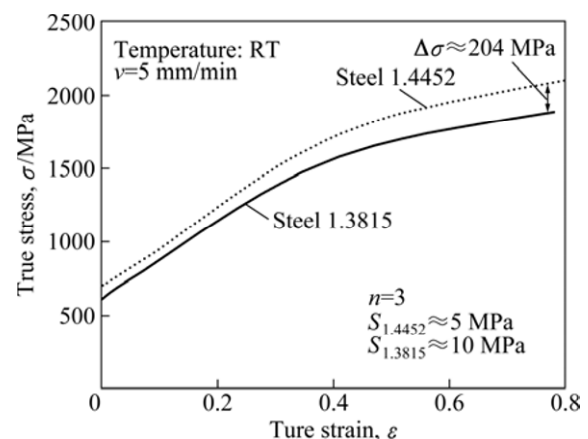


Fig. 2 True stress—true strain curves of high nitrogen steels 1.3815 and 1.4452 determined in upsetting tests

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