



# **Micro-alloyed steels for non heat treated ball studs and pins**

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International Conference on Steels in Cars and Trucks, Wiesbaden, 5. - 10. Juni 2005, p. 374/83

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## Abstract

The manufacturing sequence for ball studs can be shortened significantly by using micro-alloyed steels: annealing the wire rod before cold forming, hardening and tempering the final product are no longer necessary. Compared with the conventional process, this reduction of the manufacturing sequence has both economical and ecological advantages. The mechanical properties of these non heat-treated, cold worked products can be optimised by changing the metallurgical properties of the steel and by making appropriate modifications of the manufacturing parameters. In a project between ZF Lemförder Fahrwerktechnik GmbH & Co.KG and von Moos Stahl AG, ball studs and pins made from micro-alloyed steel called 35V1 were manufactured without heat treatment. The final parts fulfil the requested combination of mechanical properties, which are comparable to quenched and tempered steels normally used for this application (e.g. 41Cr4 for ball studs and 32CrB4 for pins). Tensile strength, fatigue and toughness can be adjusted individually by varying the area reduction during the cold drawing process of the wire rod.

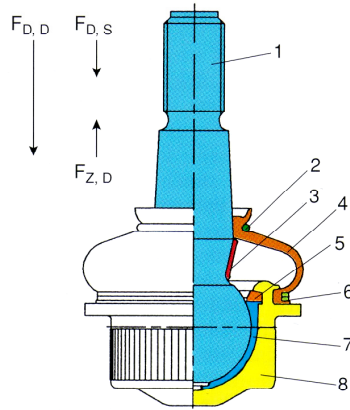
**Key words:** Ball stud, pin, micro-alloyed steel, cold heading

## 1. Introduction

Due to increasing cost pressure, suppliers for car manufacturers are being forced to make any possible attempt to reduce their production costs. The aim is to simplify or eliminate cost-intensive manufacturing schedules and to optimise the product properties.

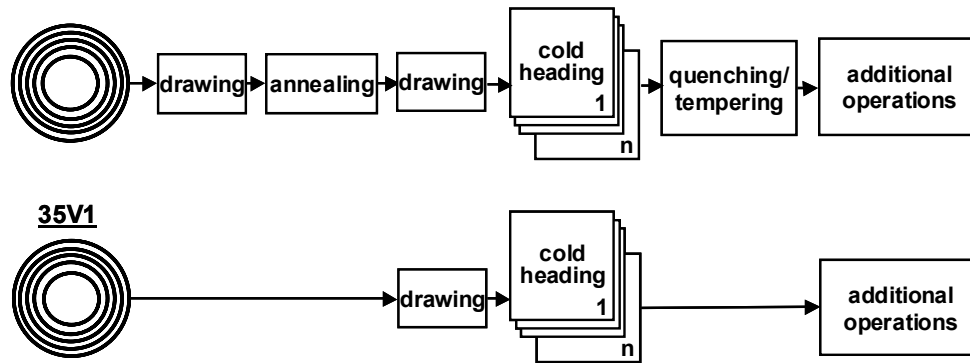
The following example - a project between von Moos Stahl AG and ZF Lemförder Fahrwerktechnik GmbH & Co. KG - shows how this goal was achieved by using a micro-alloyed steel for the production of ball studs and pins without any heat treatment.

Ball studs (**Figure 1**) and pins are important components found in ball-and-socket joints in various parts of the steering gear, e.g. transverse control arms, steering links, pin joints and stabiliser steering rods.



**Figure 1** Ball-and-socket joint, side view and half section [1]

**Figure 2** shows the most conventional process configuration for the production of ball studs and pins from wire rod using quenched and tempered steels. This process includes spheroidal annealing before the cold heading sequence, and a final quenching and tempering treatment to adjust the final properties of the product.



**Figure 2:** Process configuration for the manufacturing of ball studs and pins: conventional and without heat treatment

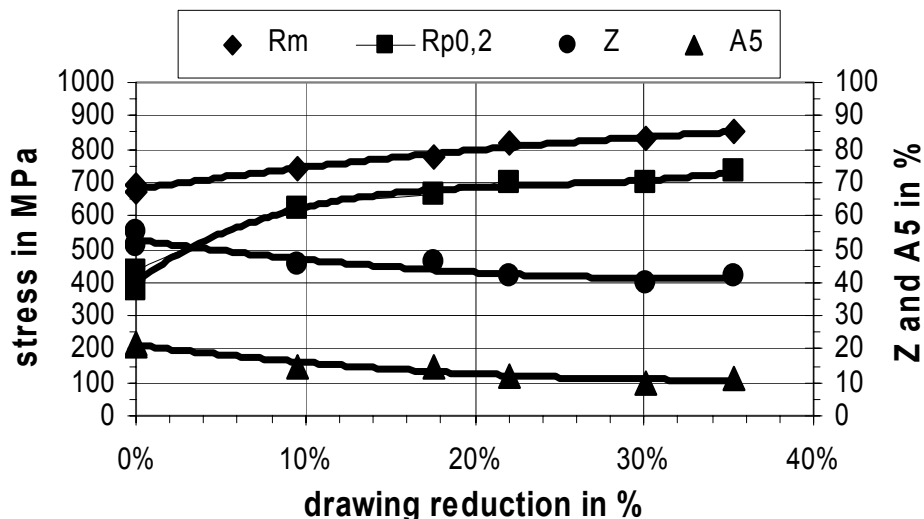
## 2. Material selection

The material typically used for the production of ball studs is 41Cr4 and for pins 32CrB4. The industrial tests, within the scope of this project, were realised using a conventionally rolled micro-alloyed ferritic-pearlitic steel called 35V1. The chemical composition of this steel is given in **Table 1**. The principal effect of the addition of V is precipitation hardening.

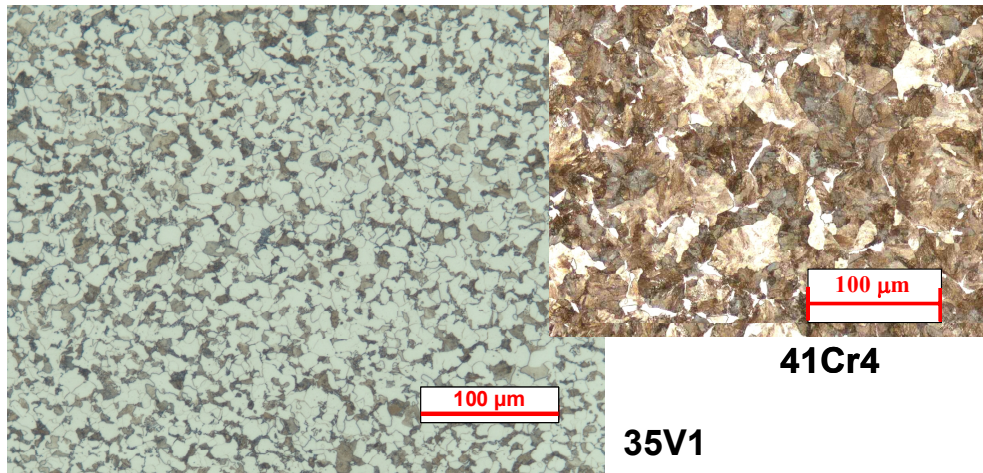
**Table 1:** Chemical composition of the steel 35V1

	C	Si	Mn	P	S	Ni	Cr	Cu	Mo	V	Al	N
35 V 1	0,35	0,20	0,75	0,02	0,02	0,15	0,2	0,20	0,01	0,10	0,02	0,01

The most important criteria for material selection to obtain the requested strength level are the final strength of the product (880-1030 MPa for ball studs; min. 1050 MPa for pins) and the strain hardening capacity of the material. The medium carbon steel 35V1 exhibits a relatively high tensile strength  $R_m$  towards 700 MPa in the as-rolled condition. **Figure 3** shows the variation of the mechanical properties of the steel 35V1 versus drawing reduction. According to these promising properties it becomes obvious, that the above mentioned strength levels for both the ball stud and pin should be achievable with rational area reductions during cold drawing of the wire rod (before the cold heading sequence).

**Figure 3:** Variation of the mechanical properties of the steel 35V1 versus drawing reduction

**Figure 4** shows the fine ferritic-pearlitic structure of the steel 35V1 compared to the steel 41Cr4, both in the as rolled condition. The grain size of the steel 35V1 is  $> 8$  according to ASTM E 112 [2], and the structure is homogeneous across the cross section of the wire rod without any bainite and/or martensite fraction. According to the Hall-Petch relation, the small grain size is beneficial for both the strength and toughness properties of the steel. Additionally it has a positive influence on the formability and increases the fatigue resistance [3]. Because of its fine structure, the steel 35V1 exhibits a reduction in area Z of more than 50% in the as rolled condition, which is an important criteria for steels for cold heading applications.



**Figure 4:** Microstructure of the steel 35V1 compared to the steel 41Cr4 in the as rolled condition

During the material selection phase, the cold heading process of ball studs was simulated using FORGE 2 to identify critical deformation areas. For these calculations, data from various flow curves were measured at different temperatures and strain rates. The simulations have shown, that the maximum strain during the cold heading sequence is not critical for the steel 35V1. Therefore all the criteria to use this steel for industrial tests were given.

### 3. Production of non heat treated ball studs and pins

The next step in this process was the production of ball studs and pins from wire rod 35V1. The components were cold formed in a 5 step cold heading sequence, that included a hexagon socket without foregoing spheroidal annealing. To examine the influence of the drawing reduction on the properties of the final parts, wire rods were tested with different reductions of area between 0 and 50 %.

After cold forming, the components were partly machined (ball studs), the thread was cold-rolled and the ball was polished. Some parts were also coated with ZnNi. This coating, if requested from the customer, can be applied to protect the parts from corrosion. After all this final proceedings the parts were ready for further testing.

## 4. Testing of product properties

### 4.1 Ball studs

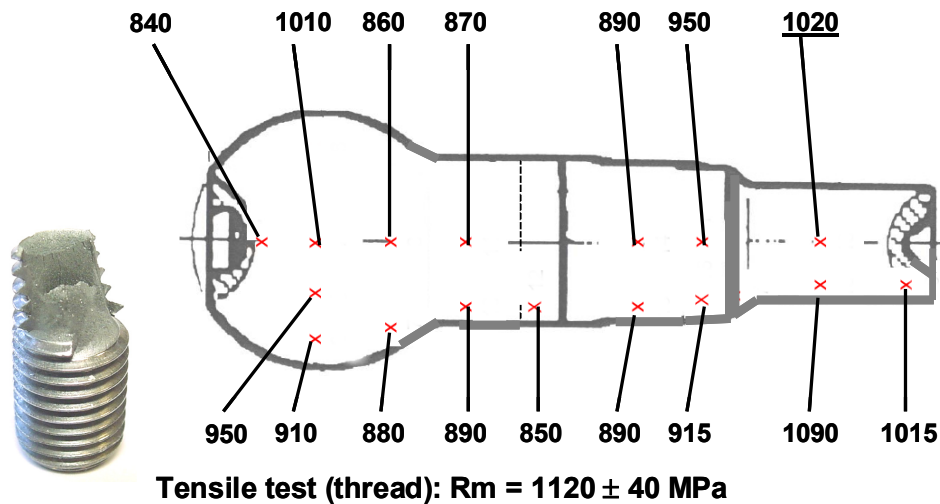
Regarding dimensioning of ball studs narrow tolerances are specified for an optimal function of the ball-and-socket joints and finally of the whole steering gear.

After a cost neutral adaptation of the manufacturing parameters, the components made of 35V1 could be processed within the specified tolerances.

#### 4.1.1 Strength

For the ball stud there is a minimum strength of 880 MPa specified. To verify this requirement, hardness values were measured on longitudinal cross sections of final parts and the mechanical properties were determined in tensile tests with small tensile specimens (rescaled as DIN 50150 [4]).

The tests have shown, that a minimum drawing reduction during cold drawing of the wire rod is necessary to meet the above mentioned requirement. **Figure 5** shows the final strength of a ball stud after a drawing reduction of the wire rod of 30% before cold heading.



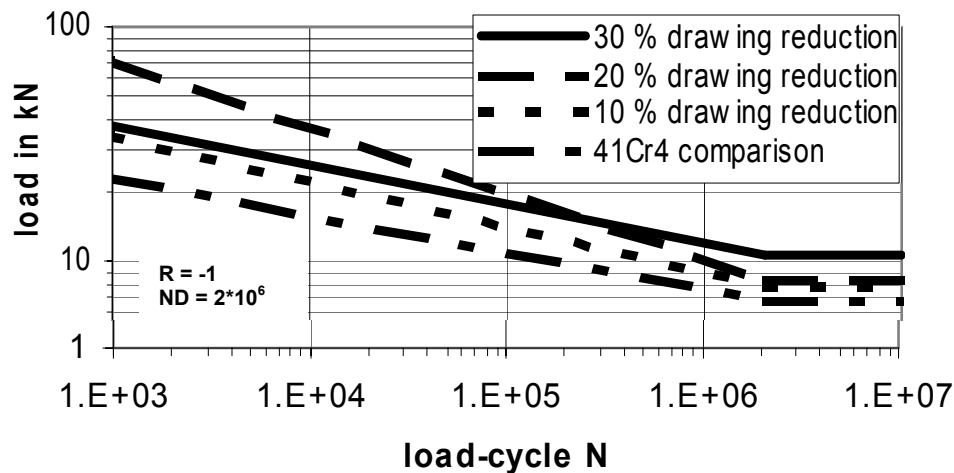
**Figure 5:** Strength (in MPa) of a cold-headed ball stud made from the steel 35V1 converted from hardness values and the strength of the thread tested in a tensile test (drawing reduction of the wire rod before cold forming: 30%)

#### 4.1.2 Fatigue resistance

Conventional ball studs in ball-and-socket joints are loaded with maximum static bending loads of 780 MPa and maximum dynamic bending loads of 190 MPa. This is also the specification for non heat treated components.

35V1 ball studs, with various drawing reductions during cold drawing (0 to 30%), were fatigue tested by applying a cyclical, tensile load. These parts were compared to identical parts made of 41Cr4 with properties obtained by heat treatment (quenching and tempering). The fatigue resistance was defined at  $2 \cdot 10^6$  cycles.

The results of the single-stage Wöhler tests and the relative fatigue behaviour of the two steels is illustrated in **Figure 6**. Due to experimental reasons, the fatigue resistance in **Figure 6** is not indicated as a function of stress, rather in applied loads.



**Figure 6:** Comparison of the fatigue behaviour of ball studs made of and 35V1 (various drawing reductions) and 41Cr4 (quenched and tempered)

Without any cold drawing, ball studs made of 35V1 achieve only approx. 85% of the fatigue resistance of quenched and tempered parts made of 41Cr4 (with a strength of 950 MPa). With a drawing reduction of 10% during cold drawing, the as-cold headed parts reveal a higher fatigue resistance than the corresponding quenched and tempered parts. With an area reduction of 30%, the results are 40% higher.

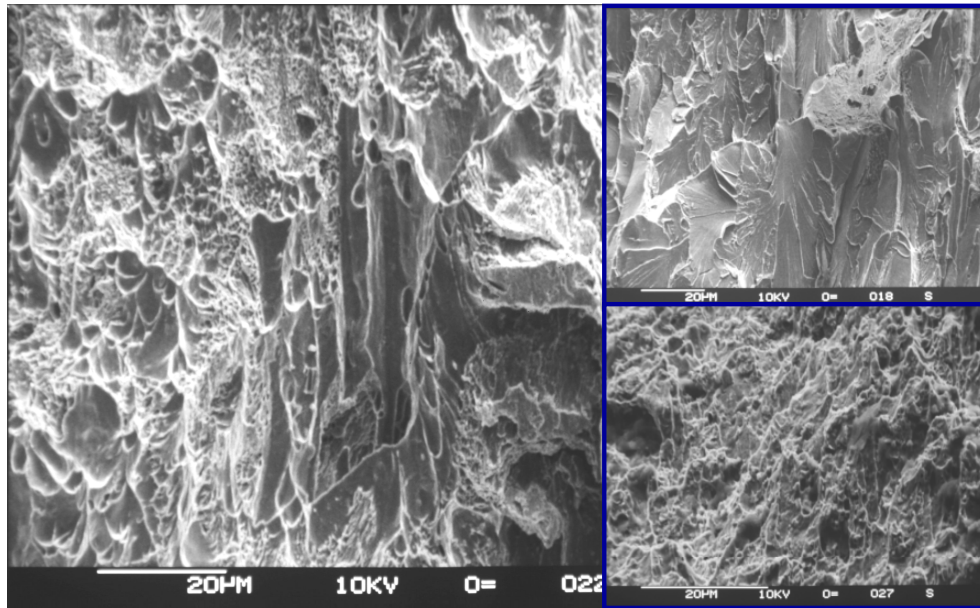
#### 4.1.3 Drop-hammer-test

Ball studs are safety-related parts and therefore require sufficient toughness properties. This properties were tested in hammering tests at room temperature and at  $-40^{\circ}\text{C}$ .

Ball studs without cold drawing before the cold heading sequence exhibit a bending displacement of approx. 12 mm at an impact energy of 400 J. The ball studs do not break before 500 J, whereas the fracture is completely ductile. Regarding impact loading the behaviour of as-cold headed balls

studs made of 35V1 is comparable to quenched and tempered parts made of 41Cr4.

An increasing of the drawing reduction before the cold heading sequence leads to a lowering of the toughness of the product. Parts made of wire rod with an area reduction of 30% during cold drawing show a maximum bending of 5 mm at an impact energy of 200 J. Impact energies > 200 J result in a breakage. SEM-images of broken balls studs (drawing reduction 30%) tested at  $-40^{\circ}\text{C}$  are shown in **Figure 7**. Large areas of the fractured surfaces show a ductile character (dimpled fracture), but there are also areas with a distinctive appearance of a brittle fracture and with a mixed morphology.



**Figure 7:** SEM-images of broken ball studs tested at  $-40^{\circ}\text{C}$  (drawing reduction of the wire rod before cold forming: 30%)

#### 4.1.4 Corrosion resistance

As expected there were no differences visible in salt spray tests [5] after 720h between coated ball studs made of 35V1 and 41Cr4 (quenched and tempered).

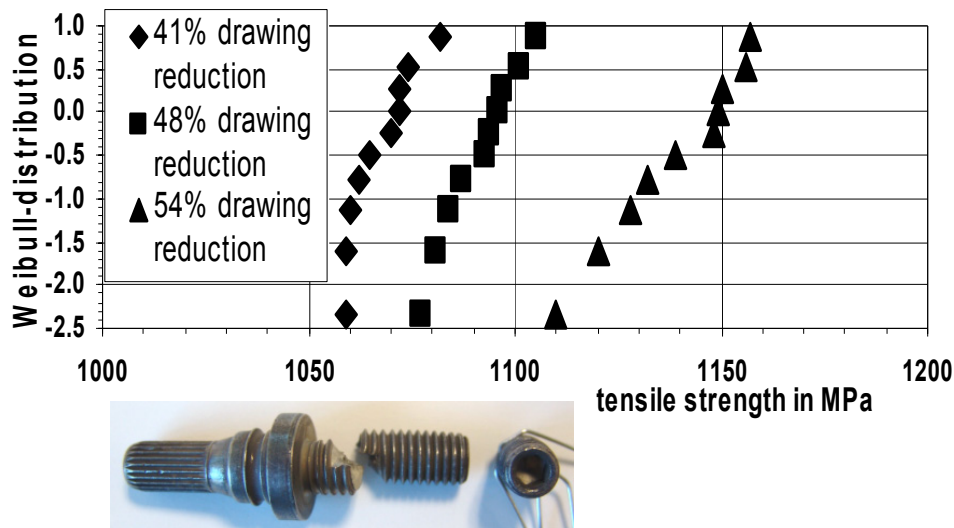


## 4.2 Pins

The parts including hexagon socket could be manufactured completely within the specified tolerances.

### 4.2.1 Strength

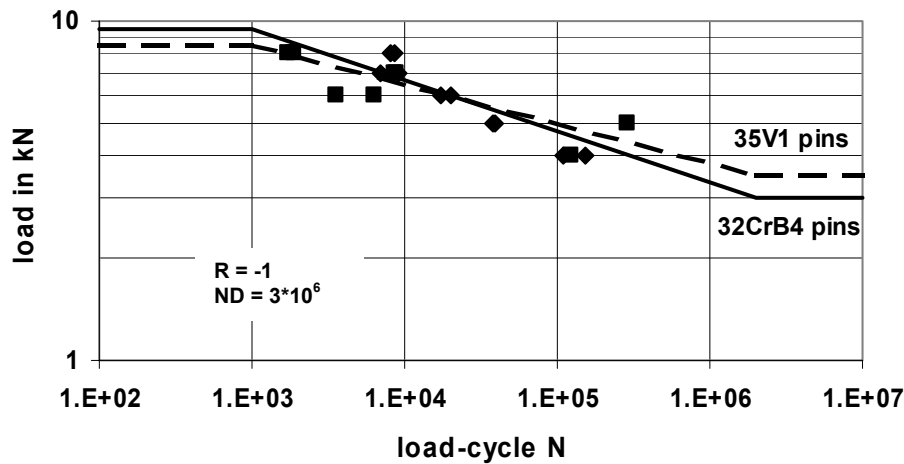
The required strength level of these products is higher than for balls studs. The minimum strength in the region of the thread should exceed 1050 MPa to guarantee a sufficient fastening torque. To determine the mechanical properties, tensile tests were performed directly on the final parts. The tests have shown that the specified strength level can only be met with a drawing reduction of more than 40% during cold drawing. Otherwise, the total deformation and the strain hardening are not sufficient. The results of the tensile tests are given in **Figure 8**.



**Figure 8:** Tensile strength of the thread (various drawing reductions of the wire rod before cold forming)

### 4.2.2 Fatigue resistance

As-cold headed pins made of 35V1 with various drawing reductions between 20 and 50% during cold drawing were tested in fatigue by applying a cyclical, tensile load. It appeared, that the pins with a drawing reduction of 20% already show a higher fatigue resistance compared to identical parts made of 32CrB4, with properties obtained by quenching and tempering (**Figure 9**). Due to experimental reasons the fatigue resistance in **Figure 9** is indicated not in stresses but in applied loads.



**Figure 9:** Comparison of the fatigue behaviour of pins made of 35V1 (drawing reduction of the wire rod before cold forming: 20%) and 32CrB4 (quenched and tempered)

There was no need to perform drop-hammer-tests because pins are not safety-related items. Also corrosion tests were not carried out because the same results as for ball studs can be expected.

## 5. Summary

The results obtained in this project show that it is possible to manufacture as-cold headed parts like ball studs and pins under industrial conditions without the need to quench and temper the final product. This could be achieved by using a micro-alloyed ferritic-pearlitic steel named 35V1. The resulting simplifying of the sequence of cold forming leads to substantial economical and ecological advantages.

The industrial tests presented in this paper demonstrate that the mechanical-technological properties of the non heat treated cold heading parts meet the specified requirements and are comparable with conventionally produced components made of quenched and tempered steels (i.e. 41Cr4 and 32CrB4).

The final properties of the products can be systematically optimised by appropriate modification of the manufacturing schedules. Testing showed how the mechanical properties of the final product can be influenced through drawing reduction on the wire rod before the cold heading sequence. It was revealed that there is a certain drawing reduction necessary to achieve the specified strength level in the final part. Furthermore the drawing reduction also allows to adjust and optimise the strength-toughness-ratio depending on the specific product requirements.

## **6. References**

- [1] Nikolaus Fecht: Komponenten für Fahrwerk und Lenkung, Verlag moderne Industrie, Landsberg 1997
- [2] ASTM E 112 (1996)
- [3] Dahl, W.: Verhalten von Stahl bei schwingender Beanspruchung, Verlag Stahl Eisen GmbH, Düsseldorf 1978
- [4] DIN 50150, Tab. A1
- [5] Salzsprühtest nach DIN 50021