

## **Stainless Steel Ball Pins in Chassis Components**

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### **Summary**

Today it has become standard practice particularly in premium vehicles to protect ball pins from corrosion by coating it completely (e.g. by nitriding). Therefore most of the parts are carbonitrided at external surface coating companies.

A general disadvantage of coated ball pins is that the basic material can continue to corrode, e.g. after the coating has been damaged.

There is a desire for alternative robust solutions. One option is the use of ball pins made of stainless steels, wherein these pins must meet the existing mechanical and physical requirements and may not be priced much higher than nitrided pins.

Austenitic stainless steel grades did not achieve acceptance for ball pins to date due to insufficient tribological properties and the cost.

By using an affordable ferritic stainless steel (1.4003), ball pins were able to be cold forged economically, eliminating the relatively cost intensive process steps of annealing, quenching and tempering, and nitriding. The mechanical-technical characteristics and the corrosion resistance of these ball pins are comparable to carbonitrided parts made of quenched and tempered steels manufactured conventionally.

Key words: ball joint, ferritic stainless steel, cold forging, static and dynamic strength.

# 1. Introduction

The conventional manufacture of ball pins made of quenched and tempered steel – e.g. material 41Cr(S)4 or 42CrMo(S)4 – is shown in **Figure 1**. Since the mid 1990's, it has become standard practice particularly in premium vehicles to protect the ball pin from corrosion by coating (nitriding) it completely [1]. A general disadvantage of the coating process is that the basic material can continue to corrode, e.g. after the coating has been damaged. The chain of damage in the vehicle, however, is structured in such a way that no surface damage is sustained even during special driving maneuvers.

There is a desire for alternative robust solutions. One option is the use of ball pins made of suitable stainless steels. The intended manufacturing process for ball pins made of stainless steel is shown in **Figure 1**.



Figure 1: Elimination of process steps by using stainless steels as an alternative to nitrided quenched and tempered steels

# 2 Material selection

There are, e.g. austenitic stainless steels with very good corrosion resistant properties and very high toughness. These steel grades, however, are on the one hand fairly expensive and difficult to machine, and on the other, they do not have the desired joint properties.

For the large-scale testing, wire rods made of standard Cr steel with material number 1.4003 was used to manufacture the ball pins whose chemical composition in conjunction with an adapted rolling process was designed to meet the requirements. The ZF internal standard designation of the steel is X1CrNi12. The homogeneous and primarily ferritic/martensitic structure of the modified steel X1CrNi12 is shown in **Figure 2**. It is the result of a chemical composition specified more exactly than the standard.



Figure 2: Microstructure of the X1CrNi12 stainless steel in as-rolled condition

The steel is characterized by a fine-grained and uniform structure as rolled, sufficient hardness, adequate strain hardening behavior and satisfactory deformability. The rolled wire at a tensile strength of 800 MPa has a 20% elongation at failure and an over 60% area reduction at fracture.

### 3 Production of ball pins

Ball pin blanks are pressed from the drawn X1CrNi12 wire without subsequent annealing in a 5 to 6 stage cold forging process. By selecting the drawing reduction prior to cold forging and the layout of the individual forming stages, the local mechanical-technical properties of the part can be achieved.

The pressed blanks are partially or completely stripped in the automatic lathe. Machining is done without coolant using standard lathe tools and machining programs with standard cutting speed, feed motion and chip thickness. Thread rolling as well as the polishing of the balls is then also done on standard roller-burnishing machines.

### 4 Manufactured ball pin made of X1CrNi12

**Figure 3** is an example of a sophisticated ball pin with undercut neck and pin extruded to the finished size, thread roll diameter, chamfer and hexagon socket. High production capacity was able to be pressed without noticeable tool wear or tool/stamp breakage.

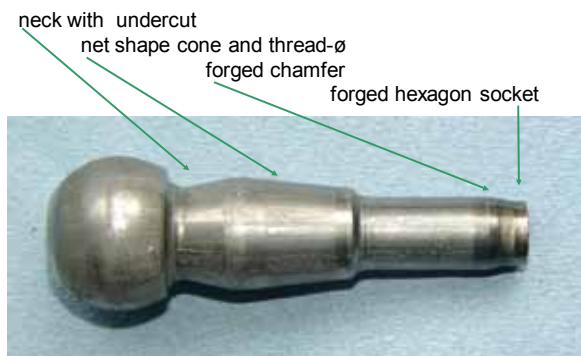
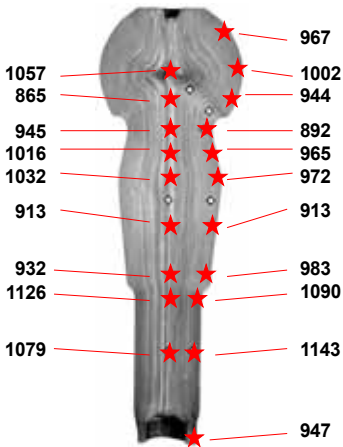


Figure 3: Pressed ball pin blank with undercut neck and hexagon socket



For the threaded section of the ball pin, a minimum strength of 820 MPa is required for nitrided ball pivots. The hardness values determined on the longitudinal cross-section are shown in **Figure 4**. It has been shown that the required strength in the threaded section has clearly been met with over 1000 MPa.

Figure 4: Tensile strengths at various measuring points in longitudinal section calculated from the hardness according to DIN EN ISO 18265 Tab. A1

In the joints, the ball pins are primarily subjected to stress by reversals of bending. The maximum bending stresses (static and dynamic) for conventional ball pins must at least be met also by the alternative material. The fatigue limit of the ball pins was determined in a single-stage Wöhler fatigue test using a continuous alternating load wherein the fatigue strength is defined at  $2 \cdot 10^6$  load cycles.

**Figure 5** compares the 50% component S/N curve for ball pins made of X1CrNi12 and 41CrS4 annealed to 950 MPa of the same geometry. The open symbols represent 2 fatigue-tested specimens without rupture.

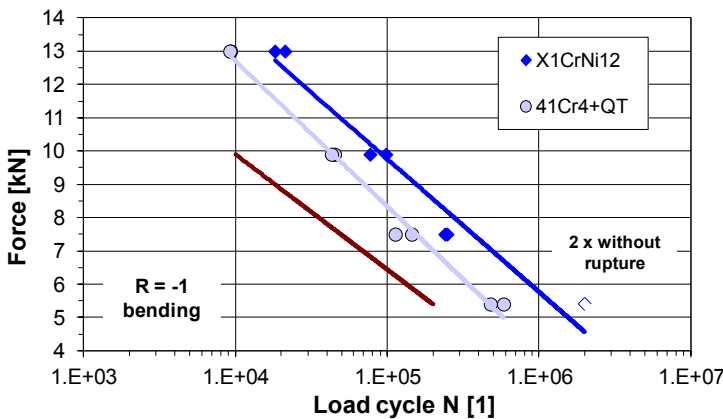
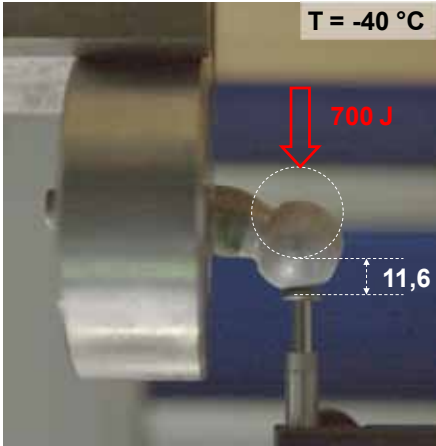


Figure 5: Comparison of fatigue behavior of ball pins made of 41Cr4+QT (quenched and tempered) and X1CrNi12. Target specification according to specification (R = -1; open symbols: fatigue resistant)

The greater fatigue limit of the X1CrNi12 compared to the 41Cr4 despite the lower yield stress can be explained by the better globular structure and the finer grained

material [2]. The number of cycles endured before rupture is approx. 10 times higher than the number required by the specifications.



Based on the damage chain, defined parts in the chassis are to be ductile in the event of excessive loading. If the ball pin assumes this task in the damage chain, it may not fail due to low ductility. To test this criterion, the behavior of the ball pin made of X1CrNi12 was tested at low temperatures under impact stress.

**Figure 6** shows the determined deformation of the pin after the drop-hammer test. The ball pins were able to be struck with up to 700 J.

Figure 6: Measurement of cack-free permanent deformation of the pin (11.6 mm) after drop-hammer-test at -40°C and 700 J

With this amount of energy, the ball pins were already so deformed (11mm to 12mm) that further testing with higher energies was no longer possible. No cracks were able to be seen on the the pin and after metallographic longitudinal cross-sections were reviewed.

The materials preferred for use in the chassis are aluminum forged alloys, steels and cast iron. Since the stainless steel ball pins are very different from these materials in the electrochemical series, ball pin blanks made of X1CrNi12 were assembled to disks made of aluminum (AlMgSi1-F40) and gray cast iron (EN GJS-500-7, old GGG40) with electroplated screws and aged up to 10 cycles in the VDA alternating climate test [3] or up to 480 h in neutral salt spray testing [4]. The results of salt spray testing and the alternating climate test did not vary significantly. In both variants, the stainless steel ball pins and the nuts belonging to them were only slightly corroded. After the corrosion test, the nuts were unscrewed. The nuts on the stainless steel ball pin were able to be turned out by hand of the pin after being unscrewed using the torque wrench. To simulate the connection to a wheel carrier, bearing or swivel bearing, the X1CrNi12 pins were assembled to a rod made of gray cast iron by means of a clamping joint (**Figure 7**). These samples were then corroded for 10 cycles in the VDA alternating climate test. The gray cast iron rod was very corroded, while the ball surface of the X1CrNi12 ball pin was still shiny after polishing with a soft cloth.



Figure 7: Corrosion of a pin made of X1CrNi12 after 10 cycles in a VDA alternating climate test, assembled in GGG40

Another gauge for evaluating contact corrosion is the electrochemical potential. A large potential difference between two metals means a greater tendency of the base metal to dissolve. The electrochemical potential of ball pins made of various steel alloys or coatings was tested in indoor air in vented salt water (250 g NaCl in 1000 g water) at room temperature against the aluminum alloy AlSiMg1. An uncoated pin has a potential of 0.15 V while an X1CrNi12 pin has a potential of 0.35 V compared to the Al alloy. Pins with GNC or QP coating have a potential of approx. 0.5 V. The austenitic steel X3CrNiCu18-9-4 is well-suited to cold forging, but in this comparison it has the greatest electrochemical potential (+0.55 V). The best corrosion protection in regard to contact corrosion is the steel X1CrNi12.

Joints using ball pins made of X1CrNi12 exhibit the same joint properties (pursuant to the specifications of the AK-LH 14 [5]) as joints with nitrided pins. If, however, pins made of austenitic stainless steels are used, basic testing using a ball-prisma-tribometer reveal that scoring develops rapidly between the pin and the ball socket.

**Figure 8** shows the coefficient of friction measured over the friction path for balls of both steels. Both the grease as well as the material for the arrangement consist of series material.

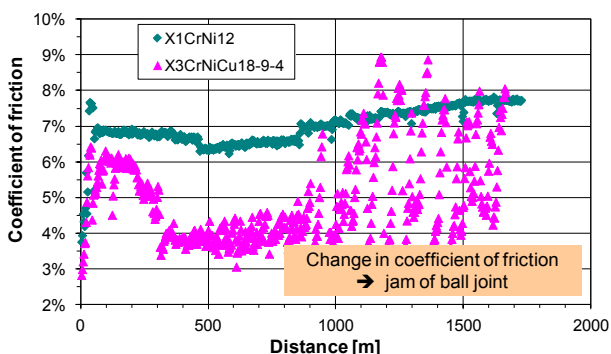


Figure 8: The coefficients of friction in the ball-prisma-tribometer for austenitic steel X3CrNiCu18-9-4 and ferritic steel X1CrNi12 versus greased POM

The coefficient of friction of ferritic steel is constant while the coefficients of friction for austenitic steel fluctuate greatly, which is an indication of scoring of the friction pairing. After the test, the joint lubrication changes into a dark color in the presence of the austenitic pin, while it stays light if the pin is made of X1CrNi12 (**Figure 9**). There are also definite jamming and wear marks on the ball surface of the austenitic stud that is attributable to tribological oxidation. No striking marks were discovered on the ball surface of the ferritic pin. Jamming layers may also form on the ferritic pin under great tribological stress.



**X3CrNiCu18-9-4**

**X1CrNi12**

Figure 9: Friction behavior of austenitic steel X3CrNiCu18-9-4 and ferritic steel X1CrNi12 in ball-prism-tribometer versus greased POM after a friction path of 1700 mm

## 5. Further advantages

Further non-technical economic and ecological advantages by manufacturing ball pins in X1CRNi12 stainless steel are:

- Elimination of the processes of annealing, quenching, transport, coating
- Shorter processing time and thus an ability to react faster to fluctuations in production (warehousing principle)
- Less tied-up capital
- Lower testing costs (since quenching and coating are eliminated)
- Efficient use of resources and energy, CO<sub>2</sub> reduction

The costs for manufacturing cold forged ball pins and eliminating cost-intensive process steps always depend on the specific part. The economic efficiency of the entire manufacturing chain is a given in view of the described development due to the savings compared to conventionally manufactured parts.

## 6. Conclusion

It has been shown that the process chain in the manufacture of ball pins can be shortened considerably by selecting the right material and considering the complex demands. By using X1CrNi12 stainless steel, the manufacturing steps of annealing, quenching and tempering and coating can be eliminated. The parts themselves can be machined using conventional machines and tools without substantial additional expenditure. Evidence has been provided that the properties of ball pins made of X1CrNi12 are comparable to those of conventionally manufactured parts made of quenched and tempered steels and all requirements for the product are met.

An important requirement for the success of a project such as this is the intensive, interdisciplinary cooperation of all involved over the entire process chain.

## References

- [1] Kruse, J. Spurstangenkomponenten, Werkstoffe und Herstellung im Wandel der Zeit, 14. Sächsische Fachtagung Umformtechnik, Freiberg, 4.-5.12.2007.
- [2] Dahl, W. Verhalten von Stahl bei schwingender Beanspruchung; Verlag Stahl Eisen GmbH, Düsseldorf 1978.
- [3] N.N. VDA Wechselclimatest.
- [4] N.N. Salzsprühtest nach DIN 50021.
- [5] N.N. Arbeitskreis - Lastenheft Fahrwerksgelenke AK-LH 14; Audi AG, BMW AG, DaimlerChrysler AG, Porsche AG, Volkswagen AG; Dez. 2004.