GRW

High-Precision Ball Bearings

KAMAN

Specialty Bearings & Engineered Products

BEARING STEELS FOR 21ST CENTURY AEROSPACE: X65CR13 VS 440C

The aerospace industry continues to drive manufacturers to provide bearings that are able to withstand the harsh conditions of both aviation and space. Every tool, material, and procedure used in aerospace goes through detailed testing and documentation to substantiate its ability to function with optimal efficiency in our skies. Requirements for rolling-element bearings include:

- Ability to operate in extreme temperature ranges
- High reliability to achieve a long operating life

Bearing manufacturers research and test different steel grades and hardening techniques to enhance the properties of their component materials; however, these efforts are futile when providing a bearing solution that is limited to the specifications on either an outdated drawing or print. The goal of this paper is to provide substantiation for SS (X65Cr13) stainless steel as a viable ring material through its comparable properties to that of the commonly used AISI S (440C) stainless steel.

The bearing industry has used AISI 52100 steel as a standard material since 1920 with its commonly accepted hardness of 58 Rockwell C. (Zaretsky, 1982) With improved bearing manufacturing, steel processing and lubrication technology, today's bearings can have a lifespan:

- 80 times that of bearings in the late 1950s
- 400 times that of bearings in the 1940s (Zaretsky, 2021)

Steel manufacturing became a focus in the 1950s for both the aerospace industry's advancement of the aircraft gas turbine engine and NASA's mission to provide products made with steels that could withstand the vacuum conditions of space. With the limited capacity to provide maintenance on shuttles and other space equipment when in orbit, bearing life and life-cycle costs continue to increase criticality. Additionally, Although corrosion resistance is not typically a functional requirement, its impact on life-cycle cost makes it a focus when choosing steels. Alloy steels with high chromium content (greater than 12 percent) are considered to be corrosion resistant with their ability to form a passive chromium oxide layer at the surface of the material. (Zaretsky, 2012)

THE LEGACY MATERIAL – 440C

For applications with temperatures less than 149°C (300°F), like the cryogenic turbo pumps on rocket engines on the NASA Space Shuttle, 440C has been the legacy corrosion resistant steel of choice. (Zaretsky, 2012) 440C grade stainless steel was introduced to provide a high-carbon, martensitic stainless steel, that when tempered meets expectations in its strength, hardness properties, and corrosion resistance.

A recognized strength to 440C comes with its low value of retained austenite (<7%) which is an important factor for dimensional stability in aerospace. Tempering procedures help remove peak stresses and retain maximum Rockwell C hardness above 58; however, many advantages to using 440C are lost when exposed to operating temperatures above 400°F. (GRW, 2020) In addition, the large chrome carbides within 440C can contribute to a slightly noisy behavior within the bearing. (AST, 2010) Despite potential increased noise behavior, 440C is approved through its conformity with AMS 5618 on prints as a legacy stainless steel ring material for ball bearings in low-temperature aerospace applications.

DEVELOPMENT OF X65CR13

The 1980s introduced advances in steel hardening and composition development across steel manufacturers. Through tempering and material composition, a new stainless steel, X65Cr13 was developed which had comparable mechanical properties (as shown in Table 1) and superior noise performance to that of 440C.

X65Cr13 is another martensitic stainless steel which has less carbon and chromium in its composition when compared to 440C (also known as X105CrMo17). (GRW, 2020) Advanced bearing companies throughout the world, including GRW, began using X65Cr13 (also referred to as X65) in the late 1980s due to its low noise and similar performance characteristics to 440C.

Properties	**SS (X65Cr13 / 1.4037)**	**S (440C / 1.3543)**
Density (g/cm³)	7.85	7.70
Hardness (HRc)	> 58	> 58
Young´s Modules (GPa)	200	215
Poisson´s Ratio	0.28	0.28
Expansion Coefficient ($\times 10^{-6} K^{-1}$)	10.1	10.4
Temperature Resistance (°C / °F)	0,5	0,5
Corrosion Resistance	conductor	conductor
Magnetism	magnetic	magnetic

Table 1. Mechanical properties of X65Cr13 vs 440C

DIRECT COMPARISON OF 440C AND X65

One of the advantages of having 440C as a ring material is its resistance to corrosion when exposed to applications with severe or unknown environmental factors. A common way of testing a steel's corrosion resistance is through salt spray testing.

GRW performed a Neutral Salt Spray test (per DIN EN ISO 9227) on four commonly-used ring material steels (including 440C and X65) with the goal of assessing their corrosion resistance over a controlled amount of time in a test cabinet environment.

The results (shown in Figure 1) show corrosion propagating around the same timeframe and continuing on a similar trajectory with 440C slightly outperforming X65.

Comparing these results to the other two steels, 100Cr6 chrome and Cronidur 30 (SV) there is not a noticeable difference in corrosion damage between 440C and X65.

Similarly, (in Figure 2) the static load capacity performance of X65 is slightly inferior to 440C; X65 will start to depreciate before 440C, but at a slower rate as they approach plastic deformation. To summarize both tests, the results that marginally favor 440C over X65 are negligible in real world applications.

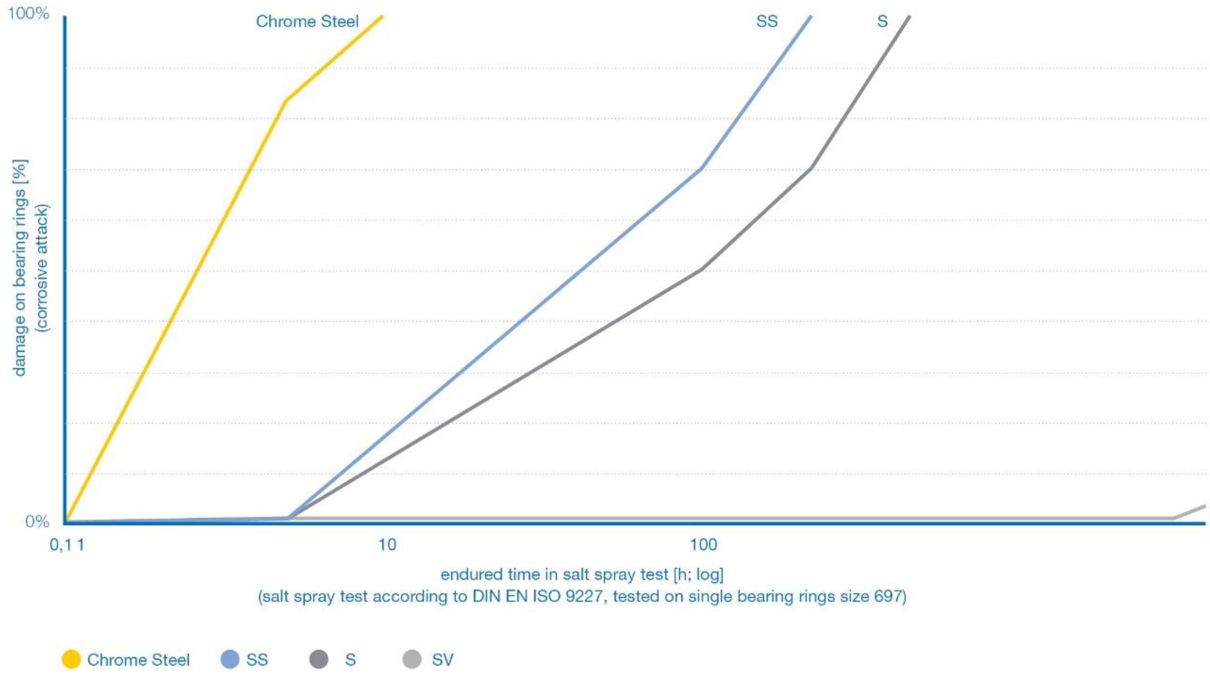

Figure 1. Corrosion Resistance of GRW Bearing steels per Salt-spray testing

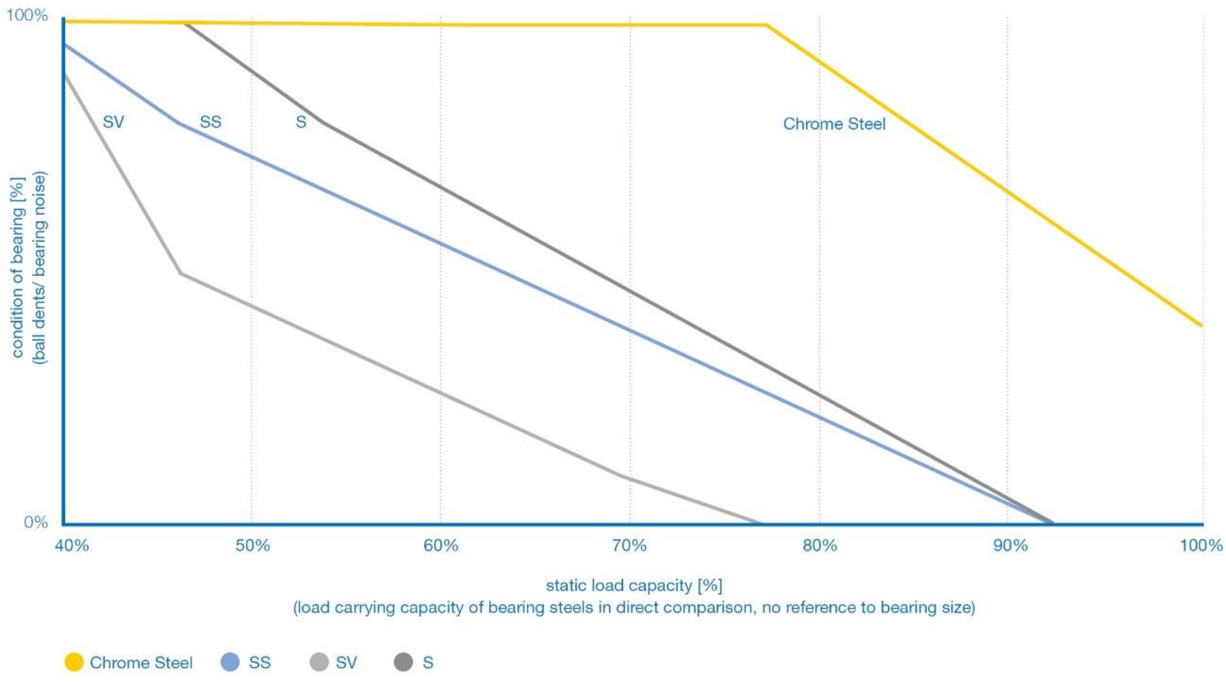

Figure 2. Static load capacity of bearing steels

When viewing the microstructure (in Figure 3 per DIN 50602 method K) of both steels at a high magnification, X65 was revealed to be more refined with a smaller and homogenous dispersion of carbides when compared to 440C. The absence of voids in the X65 microstructure support a more consistent finish and results in:

- Lower bearing operating noise
- Reduced vibration

The advantages discovered in X65 material has proven to be critical in various aerospace applications.

Stainless Steel Microstructure

SS (X65Cr13) S (440C)

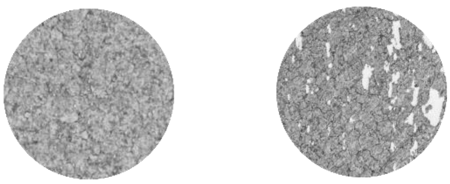

Figure 3. Microstructure comparison of SS (X65Cr13) and S (440C)

X65: A COMPARABLE AND VIABLE ALTERNATIVE TO 440C

The combination of comparable load capacity and corrosion resistance, with decreased noise and friction help make a case for X65Cr13 as a viable stainless steel ring material for miniature ball bearings in aerospace applications that currently utilize 440C.

Unfortunately, X65 is not recognized in the aerospace industry through AMS compliance standards, and this lack of recognition results in difficulty revising prints for bearings that demand 440C as their only option for ring material to support an application.

Approving a stainless steel can be a long, investigative process, and this paper comparing the mechanical properties and critical characteristics for an application will be a significant step in the approval process.

References

- E. Zaretsky, "Development of High-Speed Rolling-Element Bearings - A Historical and Technical Perspective," NASA Lewis Research Center, Cleveland, Ohio, NASA Technical Memorandum 82884, June 1982.
- E. Zaretsky, "Rolling Bearing Steels – A Technical and Historical Perspective," NASA Glenn Research Center, Cleveland, Ohio, 2012.
- "GRW Bearing Materials" GRW High-Precision Ball Bearings, 2020, https://www.grw.de/files/grw/FINALE%20BILDDATEN/INFOTHEK/DOWNLOADS/BROSCHUEREN/EN/Bearing%20Materials.pdf
- "Bearing Materials – Ceramics, Chrome Steels, Stainless Steels, And Plastics." AST Bearings, 2010, https://www.astbearings.com/bearing-materials-ceramics,-chrome-steels,-stainless-steels,-and-plastics.html