AluVaC®: All-Aluminum CF Components and Chambers
Part 1 – EN

Knife Edge Stability of CF Components made of Lightweight Aluminum

- AluVaC®: CF-compliant knife edge geometry according to ISO/TS 3669-2
- Materials yield strength and knife edge geometry are keys to knife edge stability
- Stable knife edge and He-leakage rate < 1 \cdot 10^{-10} \text{ mbar l/s after long-term testing with over 100 sealing cycles}
Knife Edge Stability of CF Components made of Lightweight Aluminum

For vacuum-tight sealing in the ultrahigh vacuum range CF components are commonly used. In order to provide a sealed connection, a knife edge shaped sealing surface is pressed into a flat metal gasket. The document at hand investigates the behavior of all-aluminum CF components (AluVaC®) in cyclic sealing processes with more than 100 sealing cycles.

Aluminum as a Vacuum Material

Due to its low density (2.7 g/cm³) and its excellent workability and machinability, Aluminum is a very attractive construction material. Therefore, the use of Aluminum in general mechanical engineering, automotive industries and building technologies has dramatically increased over the last decades. For vacuum applications, in particular in the very low pressure ranges of ultra high (UHV) and extreme high vacuum (XHV), Aluminum offers another crucial advantage – compared to stainless steel it has a naturally lower outgassing rate. Also, UHV conditions can already be achieved with bake out temperatures around 120 °C (compared to stainless steels 200 to 450 °C).

The listed advantages become particularly important in the field of all-metal sealed vacuum vessels and systems. Here, the CF flange system, where a knife edge shaped sealing surface is pressed into a flat soft-metal gasket in order to get a leak-tight connection, has been established for decades (see figure 1).

AluVaC®: All-aluminum CF components

Due to its comparatively lower hardness, the focus in developing Aluminum CF components has been on increasing the hardness and with this the scratch-resistance of flanges by adding resistant layers. Also available are CF components partially made of Aluminum, with a stainless steel knife edge. The production of this material compound is complex and cost-intensive, since a special billet has to be explosion welded prior to machining the final CF component.

Pure aluminum is known as a soft material with low strength values. However, by alloying aluminum with appropriate elements, strength and hardness can be increased significantly. So called precipitation hardening alloys undergo a special heat treatment, where the
The objective of this investigation was the evaluation of sealing reliability of the developed AluVaC® components made from aluminum. It has to be verified that even after long-term use there will be no function affecting deformation of the sealing surface.

**FEM simulations of sealing mechanisms with CF knife edge**

To determinate the optimal knife edge geometry as well as proper material specifications of sealing surface and flat gasket a model of a CF sealing system was analyzed using the finite element method (FEM) (see figure 2).

Parameter studies led to an optimal knife edge geometry within the tolerance limits of ISO/TS 3669-2:2007. A precipitation hardened aluminum alloy from the 6000 series with magnesium and silicon as the main alloying elements was identified as a proper knife edge material. For this alloy, the key parameters for sealing purposes lie in the range of commonly used stainless steels.

**Experimental determination of long-term AluVaC® knife edge stability**

In order to test the long-term stability of the AluVaC® components, blank flanges DN40CF (2.75 OD CF) made of the identified aluminum alloy, were put through numerous sealing cycles. The samples were pressed against an AluVaC® counterpart with a flat metal gasket in between. As for sealing gaskets, commonly used aluminum, copper or soft-annealed copper gaskets were applied. The screws were tightened until the flange surfaces were in contact. A leak-test of the CF sealing

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**Material** | **Alloy or alloying type** | **Yield strength [N/mm²]** | **Hardness [Brinell]** | **Notes** |
--- | --- | --- | --- | --- |
> 99 % Al | 1xxx | 62 | 32 | Soft material for metal gaskets |
Al-Mg | 5xxx | 120 | 85 | Non-hardenable |
Al-Mg-Si | 6xxx | 252 | 100 | Precipitation-hardenable |
Al-Zn | 7xxx | 358 | 134 | Limited vacuum-hardenable due to high Zn content |
Stainless Steel | 1.4404 | 220 | 175 | x |
Stainless Steel | 1.4429 | 280 | 175 | x |

**Deformation mm**

Fig. 2: Visualization of knife edge tip deformation from FEM-analysis. Different colors represent degree of axial deformation.

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Tab. 1: General data of several aluminum types in comparison to selected stainless steels
system was performed after each sealing cycle – the connection is regarded “leak-tight”, if a He-leakage rate below $1 \times 10^{-10}$ mbar l/s is obtained. At last, a conturographic measurement of the knife edge profile of both sealing surfaces was acquired at several points (see figure 3).

As a measure for knife edge deformation the flattening of the knife edge tip is regarded. This is represented by the change in the perpendicular distance $h$ from the highest point of the knife edge tip to the elongation of the flange surface (see fig. 4, left). According to ISO/TS 3669-2:2007 this measure is defined to: $h = 0.6 \pm 0.1$ mm.

All tested AluVaC® sealing pairs remained leak-tight over all sealing cycles regardless of the applied gasket material. The sealing pairs with aluminum gaskets as well as those with soft-annealed copper gaskets showed no significant flattening, not even after up to 100 sealing cycles. This is represented by the nearly congruent contours of the initial knife edge after manufacturing and after 65 sealing cycles with annealed copper gaskets (figure 4, right). All changes in distance $\Delta h$, with regard to the initial value after manufacturing, were smaller than 0.01 mm. For the absolute distance $h$, values between $h = 0.65...0.68$ mm were measured. With that, all tested AluVaC® components in use with aluminum or soft-annealed copper gaskets comply with the specification tolerances of $h = 0.6 \pm 0.1$ mm of the ISO/TS 3669-2:2007. For the absolute distance $h$, values between $h = 0.65...0.68$ mm were obtained. With that, all tested samples possess a geometry which complies with the specification tolerances of $h = 0.6 \pm 0.1$ mm of the ISO/TS 3669-2:2007.

The challenging test with non-annealed copper gaskets resulted in maximum flattening of
about $\Delta h = 0.05$ mm after 5 sealing cycles. The distance value $h$, however, was still within the tolerance range of ISO/TS 3669-2:2007. The performance of the AluVaC® components was shown by an impeccably passing of the following leak tests. Considering the higher deformation compared to aluminum and soft-annealed copper gaskets, the non-annealed copper gaskets are not recommended in application with the investigated AluVaC® components.

**Conclusion**

Identifying the proper aluminum alloy and the optimal knife edge geometry allowed the manufacturing of all-aluminum AluVaC® components. The presented investigation verifies the FEM calculations. With the identified aluminum alloy and an optimized knife edge geometry, the AluVaC® components manufactured according to ISO/TS 3669-2:2007 showed no function affecting deformation, even after more than 100 sealing cycles with soft-annealed copper gaskets. All tested AluVaC® components had measured knife edge geometry values lying reliably within the tolerance range of ISO/TS 3669-2:2007 and offered a He-leakage rate of $< 1 \cdot 10^{-10}$ mbar l/s.

The investigation showed, that AluVaC® components are the first manufactured all-aluminum CF components for the ultra high vacuum range with proven knife edge stability.

"All-aluminum CF components and chambers"

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