

Badger Meter supplies impeller axles of various materials, some based on our own experience and some to meet specific user needs. To provide more information to our clients and to rationalize the selection of the best material for a specific application, we have undertaken a series of tests to provide data that is not readily available to the field.

Materials Tested:

Zirconia Ceramic (ZrO₂)
316 Stainless steel
Tungsten Carbide (Cobalt binder)
K Mone®
Titanium
Hastelloy® C
Tantalum

Corrosion resistance tests were performed on each of the above axles. Seven different reagents that are commonly found in industrial processes were used in these test. Test were also performed for wear resistance by using a sand slurry.

REAGENTS AND EQUIPMENT USED IN TESTING

A 25 % solution of four (4) acids and two (2) bases, and a 0.5 M solution of Ferric Chloride (FeCl₃) were used in the corrosion test. These were:

Bases:

Hydrochloric (HCl)
Potassium Hydroxide (KOH)

Acids:

Nitric (HNO₃)
Sodium Hydroxide (NaOH)
Phosphoric (H₃PO₄)
Sulfuric (H₂SO₄)
FeCl₃ Recipe: 135.2 g of FeCl₃·6H₂O, dissolved in water containing 20 ml of 37.7% HCl, and diluted to 1 Liter.

The chemical resistance test used five (5) axle samples, of each material, in 150 ml of each of the above reagents. Each sample was weighed before testing started, and at irregular periods thereafter. The reagents were replaced with fresh fluids after the first 12 days of the test, and the final measurements made after 42 days exposure.

The wear test was done using a fluid made up of 100 gallons of tap water containing 5 pounds of mason sand screened to a size range of 30 to 80 mesh (0.60 to 0.18 mm). The test was concluded after 36 hours, with an average of 1,906,000 impeller revolutions.

The samples were weighed using our OHAUS Analytical Balance, Type AP110S, with an automatic calibration system, a linearity of +/- 0.1 mg., and a precision of 0.1 mg. Successive weights were measured and reported as percentage of weight lost since the start of the test. Weight losses or gains less than 0.28 mg were considered as 0.0 % loss, based on the balance precision. Weight losses in excess of that value are reported without allowance for the precision (+/- 0.1 mg) of the individual weighing operations.

TEST RESULTS

ZIRCONIA CERAMIC

Zirconia was the outstanding material for chemical resistance showing Zero percent (0 %) weight loss for all reagents except for HNO₃, where a weight *gain* of 0.01 % was measured. This was probably the result of measurement inaccuracy. In the wear test, Zirconia (0.14 % weight loss) was second only to Tungsten Carbide (0.03 % weight loss). Both materials, it is anticipated, would last the life of the sensor.

TUNGSTEN CARBIDE

Tungsten Carbide, in the test of chemical resistance, although outperformed by Zirconia, showed good resistance to bases, but was outclassed by one or more of the metallic axles in each acid environment. HCl attacked the samples most severely (2.69 % weight loss). H₃PO₄ and H₂SO₄ both showed 0.23%, and HNO₃, 0.02%. The most aggressive attack was by the FeCl₃ solution (5.03 %). Tungsten Carbide is a non metallic material in powder form (in and of itself highly inert chemically), bound together by sintering with a carrier. The available carriers are Nickel or Cobalt. The Cobalt binder is more generally resistant to chemical attack, and is the binder used in all DI Tungsten Carbide impeller shafts. In the wear test, Tungsten Carbide was the outstanding performer (0.03 % loss).

TITANIUM

Titanium, in the chemical resistance test was not an impressive performer. Significant chemical attack was noted with HCl (98.79 % loss), H₂SO₄ (17.43 %), and H₃PO₄ (4.21 %). It was relatively inert in HNO₃ with only 0.06 % loss. In bases, it displayed slight weight gain, 0.11 % in KOH and 0.06 % in NaOH. This was probably the result of chemical attack producing an inactive compound on the surface of the sample shafts. Titanium was, however, superior to Tungsten Carbide in FeCl₃ equalling the performance of Tantalum and Zirconia (0.00 % loss). In the wear test, Titanium was the worst performer (25.68 % loss).



TANTALUM

Tantalum, in the chemical resistance test was the outstanding metallic axle in an *acid* environment, showing zero (0.00 % loss) attack by any of the acids or by FeCl₃. In a *basic* environment, however, it had the worst performance of any material, 2.46 % in KOH and 0.49 % in Na OH. In the wear test, Tantalum was third, outperforming all other metallic shafts. The poor resistance to bases, and the premium price of Tantalum, should restrict its use to acidic applications where nothing else will work.

316 STAINLESS STEEL

316 Stainless, in the chemical resistance test, showed excellent resistance to both bases (0.0 % loss in both KOH and NaOH), but showed variable resistance to acids (65.58 % loss in HCl, 0.15 % in H₂SO₄, 0.00 % in HNO₃, and a 0.01 % *gain* in H₃PO₄). In FeCl₃ it lost 21.24 % of its original weight. In the wear test, Stainless, at 6.88 % loss, was inferior to Tungsten Carbide, Zirconia, and Tantalum. Indeed, its loss was almost twice that of Tantalum. *This material should be used only on specific customer request after making it clear that we do not recommend the material.*

K MONEL

K Monel® surprised us in the chemical resistance test. On our first inspection of the samples, on day 4, we were unable to find the samples in Nitric Acid. They were completely gone (100.00 % loss). In HCl, the loss was 5.31 %, in H₂SO₄, 0.59 %, in H₃PO₄, 0.37 %. The loss in FeCl₃ was the highest of all

samples, 55.42 %. Its performance in bases was much better, in KOH 0.01 % and NaOH 0.00%. In the wear test, this alloy lost 9.96 % of its weight. *This material also should be used only on specific customer request after making it clear that we do not recommend the material.*

HASTELLOY® C

Hastelloy C, in the chemical resistance test performed as expected showing excellent resistance to H₂SO₄ (0.00 % loss), H₃PO₄ (0.01 % loss), HNO₃ (.04 % loss) and HCl (0.05 % loss) acids. It was essentially unaffected by either base or by FeCl₃. However, it performed poorest of all materials in the wear test, losing 14.17 % of its weight in 1,866,000 revolutions of the impeller. *In light of its relatively poor wear resistance, the use of Hastelloy C should be restricted to those applications where it has qualified itself, by application history, as a satisfactory impeller axle material.*

SUMMARY OF RESULTS

The table below shows a summary of the results of 42 days immersion in the described reagents, and the results of the abrasive wear test, in % weight loss. Note that negative % weight loss indicates a weight gain.

REAGENT	HCl	HNO ₃	H ₃ PO ₄	H ₂ SO ₄	KOH	NaOH	FeCl ₃	WEAR
Hastelloy C	0.50	0.04	0.01	0.00	-0.01	0.00	-0.02	14.17
K Monel	5.31	100.00	0.37	0.59	0.01	0.00	55.42	9.96
316 Stainless	64.58	0.00	-0.01	0.15	0.00	0.00	21.24	6.88
Tantalum	0.00	0.00	0.00	0.00	2.46	0.49	0.00	3.45
Titanium	98.79	0.06	4.21	17.43	-0.11	-0.06	0.00	25.68
WC in Co	2.69	0.02	0.23	0.23	0.01	0.01	5.03	0.03
ZrO ₂	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.14

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