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A BadgerMeter, Inc. Company

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Impeller Axle Corrosion and Wear Resistance

Data Industrial 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 available:

DATA Industrial provides impeller axles in:

- Zirconia Ceramic (ZrO_2)
- Tungsten Carbide (Cobalt binder)
- Titanium
- Tantalum
- 316 Stainless steel
- K Monel
- Hastelloy C

Tests of each of these axle materials for corrosion resistance with each of seven different reagents commonly found in industrial processes, and for wear resistance with a sand slurry, have been conducted to quantify the relative corrosion and wear resistance of each such material.

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 ($FeCl_3$) were used in the corrosion test. These were:

Acids:
- Hydrochloric (HCl)
- Nitric (HNO_3)
- Phosphoric (H_3PO_4)
- Sulfuric (H_2SO_4)

Bases:
- Potassium Hydroxide (KOH)
- Sodium Hydroxide (NaOH)

$FeCl_3$ Recipe: 135.2 g of $FeCl_3.6H_2O$, 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 HNO_3, 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). H_3PO_4 and H_2SO_4 both showed 0.23%, and HNO_3, 0.02%. The most aggressive attack was by the $FeCl_3$ 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), H_2SO4 (17.43 %), and H_3PO_4 (4.21 %). It was relatively inert in HNO_3 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 $FeCl_3$ 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 $FeCl_3$. 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 H_2SO_4, 0.00 % in HNO_3, and a 0.01 % *gain* in H_3PO_4). In $FeCl_3$ 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 H_2SO_4, 0.59 %, in H_3PO_4, 0.37 %. The loss in $FeCl_3$ 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 H_2SO_4 (0.00 % loss), H_3PO_4 (0.01 % loss), HNO_3 (.04 % loss) and HCl (0.05 % loss) acids. It was essentially unaffected by either base or by $FeCl_3$. 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 following table 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_3PO_4	H_2SO_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

Notes and Comments:

Chemical resistance of materials is a special field of study, by itself. It is full of surprises, and often leads one astray. Reagent strength is usually directly related to the rate of attack, but not always. The presence of several corrodents often has more effect than the sum of the effects of the individuals. Static tests usually result in less corrosion than those in a flowing stream, but not always and certainly not for certain specific types of corrosion. The experience of the user is often more valid than any laboratory test, since the phenomenon is related to his unique operating environment, temperature, flow rate, mechanical loading, and the presence of additional materials that can accelerate the attack.

That being said, the writer strongly recommends that the first choice of impeller axle in any chemical environment be Zirconia. There may be cases where Zirconia will not provide an adequate axle, but I find it difficult to think where that might be. In a non-acidic environment, with entrained abrasive particles, Tungsten Carbide might provide somewhat longer life. Any user with firm belief in the superiority of another material should be encouraged to try one or the other of these axles. Finally, to add to our axle application history, we are very interested in receiving any information on environments where these materials fail.

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