From The Desk
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SELECTING ALLOYS FOR OPTIMUM TURBINE LIFE AND EFFICIENCY

BY

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ABSTRACT

Many components in hydraulic turbines are subjected to cavitation, erosion, corrosion, galling and wear. Damage to metal surfaces by any or all of these will effect efficiency of turbines, leading to considerable loss of revenue.

Whilst many engineering innovations have been incorporated in turbine design, resulting in efficiency improvements, in many cases selection of materials of construction, has remained unchanged for more than two decades.

Over this period of time a great deal of research has been carried out to understand and develop alloys with characteristics which provide enhanced resistance to wear, galling, cavitation, erosion and corrosion.

Logical selection of suitable alloys can result in a reduction of wear and damage to components, prolong turbine efficiencies and reduce maintenance costs.

WEAR & GALLING

Wear compatibility of alloys is generally expressed in terms of metal loss, arrived at by conducting tests at low stress levels. Wear decreases as hardness at the wear surface increases. However, this is not the initial or "bulk" hardness of the alloy but rather that which occurs after strain hardening, at the wear interface during sliding. Austenitic stainless steels outwear harder precipitation hardening alloys (Table 1). When comparing wear rates of self mated alloys (Table 1) with couples of dissimilar alloys, it is noticeable that wear of the dissimilar couple never exceeds the rate of the poorer of the two and almost always falls between the self mated rates (Table 2). Only in a few cases is the wear rate lower than the better of the two mated alloys.[1]

Caution should be exercised in using wear rates as sole selection criteria for mating surfaces in rotating equipment, as some alloys which exhibit good wear rates, have poor resistance to galling. Unlubricated galling resistance of stainless steel alloys[2] are given in Table 3, where it is evident that bulk hardness is not indicative of resistance to galling. For example, Nitronic 60® displays excellent resistance to galling when coupled with most stainless steels. When subjected to high loading, Nitronic 60® exhibits similar mechanisms to those possessed by cobalt based alloys, which are recognized for their outstanding resistance to wear and galling.[3]

The crystal structure of Nitronic 60® in its solution annealed condition is face centered cubic. As its strain hardens, mechanical twinning occurs subsequent to planar slip, resulting in the formation of hexagonal close packed platelets.[4] More simply stated, this alloy undergoes a change of structure, rather than fracture, when subjected to input of mechanical energy.

In another series of tests[5], aluminum bronze, a relatively soft alloy (RB90), displayed excellent resistance to wear and galling. This alloy did not gall when stressed to 50 ksi, mated with austenitic, martensitic and ferritic stainless steels. CA6NM galled against stainless steels at 2-3 ksi, but when mated with Nitronic 60, galling did not occur until stressed to 39 ksi.

These results would seem to be supported in data generated by U.S. Army Construction Engineering Research Laboratory relating to selection of wear ring couples.[6] It was concluded that mating alloys of aluminum bronze and Nitronic 60 would be a primary selection in resisting wear, galling and cavitation.

Table I

Wear Compatibility Of Self Mated Alloys Unlubricated

Wt. Loss mg/1000 Cycles

ALLOY	HARDNESS ROCKWELL	105 RPM	415 RPM
Aluminum Bronze	B87	2.21	1.52
Nitronic 60	B95	2.79	1.58
Type 301	B90	5.47	5.70
Type 304	B99	12.77	7.59
Type 310	B72	10.40	6.49
Type 316	B91	12.50	7.32
17-4 PH	C43	52.80	12.13
CA 6 NM	C26	130.0	57.0
Type 410	C40	192.79	22.50

TABER MET-ABRADER 0.5" CROSSED CYLINDERS, 16 LB LOAD

[Shoemaker ']

Table 2

TABER MET - ABRADER 0.5" CROSSED CYLINDERS, 16 LB LOAD, 105 RPM
WT. Loss mg/1000 Cycles

	Self Mated	Couple
Type 304 (B99)	12.77	25.0
17-4 PH (C43)	52.8	
Type 304 (B99)	12.77	6.00
Nitronic 60 (B95)	2.79	
17-4 PH (C43)	52.8	1.36
Alum Bronze (B87)	2.21	
17-4 PH (C43)	52.8	5.46
Nitronic 60 (B95)	2.79	
Nitronic 60 (B95)	2.79	1.64
Alum Bronze (B87)	2.21	

[Shoemaker ']

Table 3

UNLUBRICATED GALLING RESISTANCE-THRESHOLD GALLING STRESS(k.s.i.)

Button And Block Test - Single 360° Rotation

Alloy	Type 410	Type 416	Type 430	Type 440C	Type 303	Type 304	Type 316	17-4PH	Nitronic 60
Hardness B.N.H.	352	342	159	560	153	140	150	415	205
Type 410	3	4	3	3	4	2	2	3	50+
Type 416	4	13	3	21	9	24	42	2	50+
Type 430	3	3	2	2	2	2	2	3	36
Type 440C	3	21	2	11	5	3	37	3	50+
Type 303	4	9	2	5	2	2	3	3	50+
Type 304	2	24	2	3	2	2	2	2	50+
Type 316	2	42	2	37	3	2	2	2	38
17-4 PH	3	2	3	3	2	2	2	2	50+
Nitronic 60	50+	50+	36	50+	50+	50+	38	50+	50+

Hardness Applies To Alloys On Both Horizontal And Vertical Axes
[Baltimore Specialty Steels ']

+Denotes: Did Not Gall

CAVITATION EROSION

Many studies on cavitation/erosion have been conducted employing different methods of testing, but overall results are surprisingly similar, not only in the order in which alloys are ranked, but also in relative metal loss. Although the nature of cavitation and erosion involve different mechanisms, tests conducted by Laboratory Ultrasonic Vibration and High Pressure Jet Impingement, have proved accurate in assessing both criteria.

Table 4 is a compilation of two series of tests, conducted by employing identical ultrasonic vibration test procedures[4]; Nitronic 60® being established as the constant in both series.

Rheingans[7] produced remarkably similar results when testing stainless steel and aluminum bronze. It was demonstrated that strain hardening austenitic stainless steels possessed greater resistance to cavitation than martensitic stainless steels of a higher bulk hardness. It would appear that the cavitation/erosion resistance of austenitic stainless steels can be attributed to the low stacking fault energy of their face centered cubic structure. In austenitic stainless steel, data indicated that cavitation resistance decreased as nickel content increased. Type 301 work hardens at a faster rate than other austenitic alloys in the 300 series. Type 301 has the lowest nickel content and has been demonstrated to have better resistance to cavitation erosion than Types 304 and 308.[8] Aluminum Bronze displayed resistance equal to the best stainless steels tested and Nickel Aluminum 955 Bronze displayed slightly better cavitation resistance. These results correlate well with those of Segan[6] who, in addition, stated that 410 stainless steel performed worse than 4130 low alloy steel in the cavitation environment.

It should be noted that one exception to the overall performance of strain hardening austenitic stainless steels, is type 303, where sulphides apparently create wear debris before any significant strain hardening occurs.

A further series of tests referenced by Schumacher[9] gives some indication of similarity of results produced by different test methods (Table 5).

Table 4

RELATIVE CAVITATION/EROSION RATE

Nitronic 60	Type 304	Type 308	Type 316L	CA6NM	AISI 1020	Alum Bronze
1.00	3.67	1.89	5.67	6.80	15.44	3.00

Lab Ultrasonic Vibration Test Method 20kHz 80F(27C) H_2O 0.002"(0.05mm) Amplitude

Table 5

RELATIVE CAVITATION/EROSION RATE

CA6NM	Type 304	Nitronic 60	CA6NM	Type 316	Nitronic 60
6.8	4.7	1.0	6.6	3.7	1.0
ASTM G32 ULTRASONIC TEST			RIVER WATER JET IMPINGEMENT (28 DAY)		

European studies conducted in France[10] (Table 6) and Great Britain[11], illustrated that alloys which were common to both tests were similar in relative cavitation/erosion rate and order of rank. These co-related well to data presented in Tables 4 and 5.

Table 6

Two relatively new alloys developed to combat wear, galling and cavitation are worthy of mention.

Ireca®, an iron based alloy with low cobalt content (Table 7), is a patented alloy developed by Hydro-Quebec.[8] This alloy possesses high resistance to cavitation, due to its deformation - induced fine twinning associated with its low stacking fault energy. Ireca has been modified for use as a weld overlay under the name of Hydroloy HQ 913.®

It's resistance to cavitation compares well with alloys containing as much as 60% cobalt (Table 8), whilst displaying better weldability and improved surface grinding characteristics, similar to Type 308 stainless steel.

Table 7

IRECA - HYDROLOY HQ913 (WT%)

C	Mn	Si	Cr	Ni	Co	N
.20	10	3	17	Nil	8	0.2

Table 8

ALLOY	CA6NM	CA6NM-L	TYPE 308	TYPE 301	STELLITE 21® (54%Co)	STELLITE 6® (60%Co)	HYDROLOY®	IRECA® (Cast)
Hardness Rockwell	26C	24C	86B	90B	27C	37C	27C	26C
Erosion Rate mg/h	15	27	15	6	1.4	0.7	1.2	1.0

LABORATORY VIBRATORY EROSION TEST

Tribonic 20® is a fully austenitic iron based alloy. It cannot be classified as a stainless steel because its chromium content is low (Table 9). Initial data[12] gives its corrosion resistance as equal to that of stress relieved 410. Resistance to galling is at least equal, and in some cases superior, to that of Nitronic 60® (Table 10). Cavitation resistance is stated to be four times that of Types 304 and 316 stainless steel.

Table 9

TRIBONIC 20 (WT%)

C	Mn	Si	Cr	Ni
.03	14	5	5	5

Table 10

GALLING RESISTANCE OF TRIBONIC 20

Mating Alloy	Type 303	Type 304	Type 316	17-4 PH	Type 410	Type 410	Type 416	Type 430
Hardness Rockwell	B80	B84	B84	C43	C40	B95	C41	C39
Threshold Galling Stress k.s.i.	50.7	54.2	50.7	50.7	50.7	52.4	54.2	54.1

Button & Block Test Single 360° Rotation

Whilst further development of this alloy is necessary to ascertain its castability, weldability and machinability, there is sufficient data to encourage its consideration for use in applications such as turbine runners, seal rings, shaft sleeves and similar applications.

CORROSION

Most hydroturbines do not operate in aggressive waters where metal loss by corrosion is of primary importance, but in some cases, this may be a concern.

Corrosion, if expressed only in terms of weight loss, can be misleading. Pitting and crevice corrosion are much more insidious forms of corrosive attack. This type of attack, once commenced, tends to be self stimulating and self perpetuating. It is particularly detrimental to those alloys which rely on a surface oxide film not only for resistance to corrosion but also galling and cavitation.

Because corrosion is an electrochemical process, it can be measured, assigned a relative value or potential, and compiled in a Galvanic series. This is an excellent guide which enables engineers to select alloys which are galvanically compatible, where dissimilar couples are necessary.

Aluminum Bronze in its temper annealed condition displays excellent resistance to pitting and crevice corrosion even under stagnant conditions and in shielded areas.

Nitronic 60®, has a uniform corrosion resistance better than Type 304 in most media and it's resistance to pitting is superior to Type 316.

COST EFFICIENCY

Engineering costs incurred in modeling to ensure maximum efficiency, are high but justifiable, considering the expense involved in turbine manufacture and installation. It would not seem unreasonable that a selection process to optimize life and efficiency and minimize maintenance costs, be applied to materials of construction. Performance and efficiencies can be optimized by logical selection of materials, taking into account conditions under which individual turbines must operate.

By assigning a value or priority to those characteristics which would most effect the life and efficiency of the turbine ie: cavitation, galling, wear and corrosion, a logical process of material selection can be implemented. This may progress from the selection of runner material to combat cavitation - dependent on head and water velocity - down through choice of seal rings, shaft sleeves etc, to obtain optimum galling and wear resistance. Implementation of this, to generate alternative selections, would allow the engineer to balance increased life and efficiency against manufacturing costs.

Cobalt based alloys apart, much of the cost involved in components lies not in their alloying content, but in castability, formability, weldability and machinability. Tables 11 and 12 indicate that raw material costs of alloys becomes a less significant factor when offset by lower machining costs (Table 12).

Table 11

RAW MATERIAL COSTS OF ALLOYS BEFORE MELTING

ALLOY	Al/Bronze	Type 304	Type 316	Nitronic® 60	Type 410	CA6NM
METAL CENTS/LB	95	54	66	65	22	46

Based On Metal Prices End January 1992

Table 12

RELATIVE MACHINABILITY OF ALLOYS

ALLOY	B.H.N.	Turn, Bore Face S.F.P.M.	Drilling S.F.P.M.	Cut Off S.F.P.M.
400 Series Including 410, 420 & CA6NM	135 - 175 175 - 225 275 - 325 375 - 425	300 - 400 250 - 375 175 - 300 120 - 175	50 - 60 40 - 50 30 - 40 10 - 30	200 - 250 175 - 225 125 - 175 75 - 125
Types 304 & 316	185	175 - 275	25 - 45	150 - 200
Nitronic 60	200	175 - 275	20 - 40	130 - 175
Aluminum Bronze	175 - 215	400 - 1200	75 - 100	300 - 400

Data Generated By Wisconsin Centrifugal

Most stainless steels are readily available in all forms, but limited foundry capacity in North American has placed some limits on Aluminum Bronze castings and they have not normally been commercially available above 15,000 lbs. However, complex castings produced by static and centrifugal methods are regularly produced. Aluminum Bronze is commercially available in plate, extruded and continuous cast bars, one piece seal rings are commonly produced by centrifugally casting and ring rolling up to 200" diameter.

Care should be taken when specifying material, as Aluminum Bronze is available in a variety of specifications possessing different characteristics. The most commonly used Aluminum Bronze, C95400, should be specified to a specific temper as its hardness, ductility, weldability, and corrosion resistance will vary considerably, depending on its method of manufacture and its cooling rate. When cold formed, the alloy should subsequently be fully annealed, as machining, welding, or vibration can induce distortion resulting in manufacturing problems, or worse yet, in service failure. Similar precautions should be taken when cold forming Nitronic 60®, if dimensional stability is to be maintained.

Austenitic stainless steels have excellent formability and castability and are not difficult to machine. They display excellent weldability, maintain dimensional stability much more than martensitic steels, are far less prone to cracking and have better resistance to cavitation erosion. Data would support the selection of low nickel austenitic stainless steels over martensitic stainless steels for construction of turbine runners. Although most austenitic stainless steels display a low resistance to galling, this tendency can be greatly reduced by utilizing alloys such as aluminum bronze and Nitronic 60® for mating components such as seal rings.

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Stellite is a registered trademark of Stoody Deloro Stellite Inc.

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