MULTI Alloys

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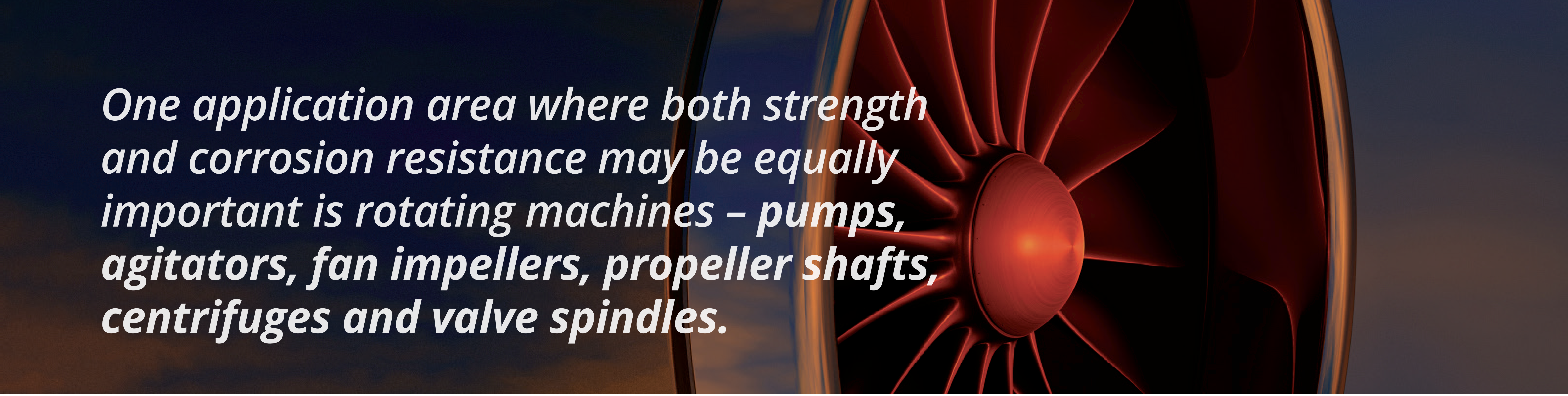
STAINLESS STEELS FOR ROTATING MACHINES

In this e-book you will learn more about grades of stainless steel that offer high strength in addition to corrosion resistance thus making them suitable for use in rotating machinery.

INTRODUCTION

A primary feature of stainless steel is corrosion resistance and whilst this may vary in line with the composition of the grades that comprise this family of alloys, it is a benefit that drives their use. A second important property affecting the selection of stainless is their strength or in broader terms, their mechanical properties. Aside from the metal's properties there are other considerations that commonly arise when selecting materials and these may include ease of fabrication, total cost and availability.



One application area where both strength and corrosion resistance may be equally important is rotating machines – pumps, agitators, fan impellers, propeller shafts, centrifuges and valve spindles.

Table 1 *is a summary of the alloys often used for this plant.* ***Table 2*** *lists their available product forms as well as their guaranteed minimum proof strength. Although the focus of this e-book is stainless steels, a few nickel alloys are included.*

Type	Grade	% Cr	%Ni	%Mo	%C	%Cu	Other
Austenitic	304L	18.0-20.0	8.0-12.0		0.03*		
	316L	16.0-18.0	10.0-14.0	2.0-3.0	0.03*		
	904L	19.0-21.0	24.0-26.0	4.0-5.0	0.02*	1.0-2.0	
	254SMO	19.5-20.5	17.5-18.5	6.0-6.5	0.02*	0.5-1.0	N;
Martensitic	420/1.4021	12.0-14.0			0.16-0.25		
	431/1.4057	15.0-17.0	1.5-2.5		0.12-0.22		
	1.4313	12.0-14.0	3.5-4.5	0.3-0.7	0.05*		N;
Precipitation Hardening	17-4PH	15.0-17.5	3.0-5.0		0.07*	3.0-5.0	Ta/Nb:
Duplex	2205	22.0-23.0	4.5-6.5	3.0-3.5	0.03*		N;
	2507	22.0-26.0	6.0-8.0	3.0-5.0	0.03*	0.5*	N;
	Alloy 255	24.0-27.0	4.5-6.5	2.9-3.9	0.04*	1.5-2.5	N;
Nickel Alloy	Alloy K500		63 Min		0.18*	27.0-33.0	Al; Ti
	Alloy 925	19.5-22.5	42.0-46.0	2.5-3.5	0.03*	1.5-3.0	Nb;Al:Ti
	Alloy C276	14.5-16.5	Bal	15.0–17.0	0.01*		W;Fe;Co

Composition data from ASTM standards for bar products. Also EN 10088-3 for Martensitics. ** Maximum*

PRODUCT FORMS

Rotating machines make extensive use of round bar for the shaft connecting the drive to the working end ie the pump or fan impeller, the agitator blades etc. However, stainless steel tubular products are also used either as the drive shaft or as a corrosion resistant cladding over an alloy steel bar. Whilst nominal bore piping, sched 40 or thicker is utilised, a practical alternative for thick wall requirements is tubular sections produced by centrifugal casting (Note 1). This same manufacturing route is used for the shell of centrifuges.

Plate is required for fan impellers and for the blades and similar items for agitators. These are fabricated items often involving welding. The design criteria for these components may be complex and involve more parameters than are covered in this review.

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Note 1: Centrifugal casting is a casting technique that is typically used to produce cylindrical items. Molten metal is poured into a rapidly spinning cylindrical mould in which the centrifugal force from the rotation exerts pressure on the molten metal which solidifies against the mould. This results in a sound metallurgical structure and after the outer and inner diameters are machined high quality components can be produced.

MECHANICAL PROPERTIES

In standards the published mechanical property data for the metals of interest are their Ultimate Tensile Strength, 0.2% Proof Strength and Elongation %. However, for shafts, which operate in torsion, shear strength is the more appropriate parameter. Fortunately, there is a direct empirical relationship between tensile strength and shear strength and thus the relative ranking of the alloys remains for the purposes of this note.

Although strength is emphasised it may well be that another mechanical property such as impact or fracture toughness needs to be optimised.

It should be noted that the strengths of the austenitic and duplex stainless steel cannot be altered by heat treatment whilst those of the martensitic and precipitation hardened grades can and thus alternative strengths for the grades in these families of alloys are possible. The same applies to Alloy C276 on the one hand to K500 and Alloy 925 on the other, the latter 2 also being amenable to precipitation hardening.

Alloy strengths and product form availability

Type	Grade	Round Bar	Plate	Tubular Sections		0.2% Proof Strength** (MPa)	Condition
				Pipe	Centrifugal Casting*		
Austenitic	304L	A	A	A	M	170	Annealed
	316L	A	A	A	M	170	Annealed
	904L	A	A	A	M	220	Annealed
	254SMO	I	I	I	M	300	Annealed
Martensitic	420/1.4021	A			M	600	QT800
	431/1.4057	A			M	600	QT800
	1.4313	I			M	620	QT780
Precipitation Hardening	17-4PH	A;I	I		M	790	H1100
Duplex	2205	A	A	A	M	450	Annealed
	2507	A	A	A	M	550	Annealed
	Alloy 255	I	I	I	M	550	Annealed
Nickel Alloy	Alloy K500	I	I	I	M	585	Ann. & Aged
	Alloy 925	I			M	758	Ann. & Aged
	Alloy C276	A;I	A;I	A;I	M	283	Annealed

AVAILABILITY KEY

A
READILY AVAILABLE

I
IMPORTED FROM OVERSEAS STOCK

M
MANUFACTURED TO ORDER OVERSEAS

**- Metal will be the cast equivalent to the wrought grade listed.*
***- Guaranteed minimum value for bar based on ASTM standards and EN 10088-3 for the martensitic grades*

CORROSION RESISTANCE

In general, corrosion resistance cannot be easily quantified by a single value. Since corrosion is the reaction of a metal with its environment, ranking of the grades needs to take account of the corrodent and service conditions. There is, however, a commonly used indicator of corrosion resistance which is an empirical relationship that is calculated using the formula

PRE = %Cr + 3.3x%Mo + 16x%N

The higher the PRE number, pitting corrosion resistance equivalent, the better this grade is at resisting this specific form of corrosion. PRE is of limited value when comparing stainless steels and nickel alloys and further comments on corrosion resistance are made in relative terms.

304L has been selected as the benchmark. It has a nominal 18% Cr and 8% Ni both of which contribute to corrosion resistance: an approximate 12% Cr content being the determinant of a stainless steel. The Ni in the alloy produces an austenitic metallurgical structure which makes it readily formable and weldable.

316L, a 17Cr-12Ni-2Mo alloy has a higher corrosion resistance than 304L and this is a result of a minimum of 2% Mo that is in the alloy. Mo enhances resistance to pitting and crevice corrosion in line with the PRE formula. Yet a further, larger increase in corrosion resistance is offered by 904L (20Cr-25Ni-4.5Mo-2%Cu) an alloy that is used in sulphuric and some other aggressive chemicals. 254SMO contains 6% Mo which, together with the nitrogen content of the alloy ensures a high resistance to pitting and crevice corrosion.

CORROSION RESISTANCE

Austenitic stainless steels are susceptible to stress corrosion cracking. However, of the grades listed, 316 and 304 are most at risk as the higher alloy content of the 904L and 254SMO renders them more resistant to this form of corrosion.

The 3 martensitic grades listed have in common that they offer higher strengths than the 4 austenitic stainless steels but with reduced corrosion resistance – in line with their chromium, nickel and molybdenum contents. However, they will not suffer chloride stress corrosion. Generally martensitic stainless steels are considered to have poor weldability but 1.4313, with its very low carbon content, is better in this respect than 420 and 431. 17-4PH is one of several stainless steels grades that may be strengthened by an "aging" heat treatment. The alloy has a corrosion resistance similar to that of 304. It is not prone to stress corrosion cracking, it is weldable and can also be aged to optimise impact toughness..

The combination of corrosion resistance, strength, weldability and the range of product available have made the duplex stainless steels very useful materials of construction for fan impellers and agitator components. The higher alloy content of 2507 results in better corrosion resistance than that of 2205 whilst the presence of copper in 255 increases this alloy's resistance to corrosion by sulphuric acid. All the grades have a high resistance to stress corrosion cracking, pitting and crevice corrosion in line with their Mo, Cr and N contents and higher strengths than the austenitic grades.

ALLOY C276 and other alloys in the "C-Family" *have excellent corrosion resistance in a wide range of aggressive media as found in the chemical and minerals processing industries, FGD plants and similar. Alloy K500, a hardenable derivative of Alloy 400, is an established alloy that is used for seawater and steam applications whilst Alloy 925 is similar to Alloy 825 but offering the combination of high strength and good corrosion resistance. The 2 high strength alloys are utilised in the offshore oil and gas industry.*

CONCLUSION

There exists a range of alloys that offer both a combination of high strength and corrosion resistance and those reviewed are some of the most common. Selecting from these and perhaps from other lesser-known alloys, the most suitable metal for use in rotating machines is part of a detailed design exercise. This will define the strength requirements to reliably withstand the operating stresses.

A benefit that may arise from the use of higher strength grades (eg duplex stainless steels) even though the lower strength options (eg austenitic grades) may suffice is that of weight saving and this in turn may offer cost benefits such as the use of a less powerful motor and simpler structural steel work and foundations.

A full appreciation of the features and benefits of the range of stainless steels available is important when material selection decisions are to be made and **We are available to assist in this regard.**

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