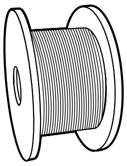
ZAPP PRECISION WIRE
INCOLOY® ALLOY 27-7MO (UNS S31277)

QUALITY SYSTEM CERTIFIED TO ISO 9001:2015



INCOLOY® ALLOY 27-7MO (UNS S31277) WIRE FOR:
_ Armoring applications on electromechanical cables
_ Wirelines for down hole service applications
_ Shaping/shaped wire for down hole well screens

CHARACTERISTICS
INCOLOY® alloy 27-7MO (UNS S31277) is a new generation "super austenitic" stainless steel offering excellent corrosion resistance in a wide variety of aggressive, down hole environments. It provides superior corrosion resistance and performance compared to the currently approved 25-6MO alloy. It contains about 7% molybdenum along with higher levels of chromium, nickel, nitrogen, and manganese, which enables it to approach the performance of much higher alloyed materials. It also represents a cost-effective alternative to the higher nickel alloys in some marine, petroleum, and chemical processing environments.

The alloy 27-7MO material contains about 27% nickel, 22% chromium, 7.2% molybdenum, 1.5% manganese, and 0.34% nitrogen. See Table 1 for chemical composition limits. The nickel and nitrogen produce a stable austenitic structure. The molybdenum, chromium, nitrogen, and manganese content offers excellent resistance to pitting and crevice corrosion.
Nickel, nitrogen, and molybdenum provide resistance to reducing media while the high chromium content offers resistance to oxidizing media. The alloy performs well in mixed acid environments, especially those containing oxidizing and reducing acids. The nickel and nitrogen content provides strong resistance to stress corrosion cracking and also attack by caustic media. The alloy offers excellent resistance to corrosion in seawater, brine, and high chloride environments. The chemical composition and balance of elements of the 27-7MO alloy produces a wire material which can provide excellent service in many of the most aggressive down hole environments. It is expected to be an ideal material for the "oil patch".

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TABLE 1 - LIMITING CHEMICAL COMPOSITION OF ALLOY 27-7MO, WEIGHT %

Ni	Cr	Mo	Cu	N	C	Mn	Fe
26.00 - 28.00	20.50 – 23.00	6.5 – 8.0	0.5 – 1.5	0.30 – 0.40	0.020 max	3.00 max	remainder

The alloy offers a unique combination of corrosion resistance, high strength, ease of fabrication, and commercial availability, all at an economical price. It provides strong improvements over 25-6MO in terms of strength and corrosion resistance with no negatives on forming or wire availability. It is expected that 27-7MO will achieve tensile strength levels greater than that of 25-6MO. Table 2 compares minimum room temperature break loads for a typical 0.108" diameter wireline of 27-7MO, 25-6MO, alloy 28, XM19, AISI 316, and MP35N®.

Chemistry Standards:
_ UNS S31277
_ ASTM A580

TABLE 2 - MINIMUM BREAK LOADS FOR A 0.108" DIAMETER WIRELINE PRODUCT

Alloy	Min. break load	Recommended safe working load (60%)
AISI 316	2000#	1200#
XM19	2110#	1266#
alloy 28	1910#	1145#
25-6MO	2130#	1278#
27-7MO	2250#	1350#
MP35N®	2300#	1380#

The 27-7MO alloy offers excellent resistance to pitting and crevice corrosion. Relative performance in these areas is often measured using Critical Pitting Temperatures (CPT), Critical Crevice Temperatures (CCT), and Pitting Resistance Equivalent Numbers (PREN). Alloys exhibiting higher PREN values are generally found to be more corrosion resistant than those with lower PREN values. The PREN can be calculated by using several different equations based upon the chemical composition of the alloys. For the comparisons in this technical summary, the following equation was used:

PREN = Cr + 3.3 Mo + 30 N

When comparing alloys by their PREN value, it is imperative that the same equation be used for all materials to be compared, otherwise, erroneous results can occur.

PREN values are listed in Table 3, comparing 27-7MO to a variety of alloys such as AISI 316, alloy 2205, XM19, alloy 28, 25-6MO, and MP35N®. Based upon these values, 27-7MO compares quite favorably to these alloys which are currently being used extensively for armor wire and wireline applications. It should be noted that the PREN value for MP35N® doesn't reflect the true comparative corrosion resistance compared to 27-7MO. MP35N® contains about 35% cobalt. Cobalt is a critical factor in terms of corrosion resistance and break strength. However, cobalt percentages are not included in the PREN formula and thus tend to skew the relative corrosion resistance results in this instance. Corrosion tests would confirm that MP35N® is superior to 27-7MO. As a point of reference, ASTM Standard Test Methods G-48 is noted. It covers the procedures for the determination of the resistance of various alloys to pitting and crevice corrosion.

TABLE 3 - PITTING RESISTANCE EQUIVALENCY NUMBERS (PREN)

ALLOY	PREN*
AISI 316	26
alloy 2205	36
XM19	38
alloy 2507	41
25-6MO	47
27-7MO	56
MP35N®	53
C276	68

*PREN = Cr + 3.3 Mo + 30N

Alloys may also be ranked by the threshold temperature at which they begin to be attacked in a given medium. Samples may be directly exposed to the medium which may induce pitting, or a crevice device may be attached which may induce crevice corrosion. The samples are exposed at increasing temperatures until corrosive attack occurs. The lowest temperature at which measurable corrosion takes place is defined as the Critical Pitting Temperature (CPT) or Critical Crevice Temperature (CCT), depending on whether or not a crevice device is attached to the sample. One test method is covered by ASTM G48. Method C is a pitting test while Method D is a crevice corrosion test. The maximum test temperature is 85°C (185°F) as the test solution becomes unstable at higher temperatures.

CPT and CCT values for some alloys are presented in Table 4 and Table 5. It is seen that alloy 27-7MO exhibits higher values than alloy 25-6MO and alloy 625 and approaches those of alloy C-276.

TABLE 4 - CPT AND CCT PER ASTM G48 TEST METHODS C AND D

Alloy	Critical Pitting Temperature		Critical Crevice Temperature	
	°C	°F	°C	°F
INCOLOY® alloy 25-6MO	70	158	35	95
INCOLOY® alloy 27-7MO	>85	>185	45	113
INCONEL® alloy 625	>85	>185	35	95
alloy C-276	>85	>185	50	122

Table 5 provides CPT and CCT test results for cold drawn armor wire. As expected, the 27-7MO alloy wire test results fall between 25-6MO and MP35N®.

TABLE 5 - TEST RESULTS OF STRESSED ARMOR WIRE IN PITTING AND CREVICE ENVIRONMENTS

Alloy	G 48 D at 25°C (crevice corrosion)	CPT in G 48 C (pitting corrosion)
25-6MO	Superficial attack	<60°C
36MO	All sites attacked	75°C
27-7MO	None	80°C
MP35N®	None	>80°C

The 27-7MO alloy wire produces higher mechanical properties than the 25-6MO alloy. Tensile strengths on the order of 220/280,000 psi can be achieved through cold drawing. At these strength levels, the wire is ductile and able to successfully pass the wrap test in the as drawn condition as well as the as drawn plus exposed to temperatures as high as 400°F conditions. This wrap or bend test shows no surface cracking or failure.
Strong resistance to stress corrosion cracking (SCC) is one of the benefits of the 27-7MO alloy wire. Table 6 lists five sets of test conditions to determine resistance of cold drawn and stressed wire to stress corrosion cracking. Table 7 presents the test results and confirms that 27-7MO has a high degree of resistance to SCC.

TABLE 6 – TEST CONDITIONS FOR EXAMINATION OF SCC RESISTANCE IN COLD DRAWN, STRESSED WIRE

Test 1	Saturated NaCl + 2.5% NH_4HSO_3 boiling for 1008 hours
Test 2	23.5% MgCl2 + 6%KCl + 0.3% CaO boiling for 1008 hours
Test 3	5% NaCl + 0.5% Acetic acid purged w/ H_2S room temp for 1008 hrs (not coupled to steel)
Test 3b	5% NaCl + 0.5% Acetic acid purged w/ H_2S room temp for 1008 hrs (coupled to steel)
Test 4	Saturated NaCl + 5%$MgCl_2$ + 5% H_2S at 350°F (177°C) and 5000 psi for 336 hours

TABLE 7 - TEST RESULTS FOR SCC RESISTANCE STUDIES ON COLD DRAWN, STRESSED WIRE

	Test 1	Test 2	Test 3	Test 3b	Test 4
25-6MO	No cracking	No cracking	No cracking	No cracking	No cracking
36MO	No cracking	No cracking	No cracking	No cracking	No cracking
27-7MO	No cracking	No cracking	No cracking	No cracking	No cracking
MP35N®	No cracking	No cracking	No cracking	No cracking	No cracking

TABLE 8 - PHYSICAL PROPERTIES OF ALLOY 27-7MO IN ANNEALED CONDITION AT ROOM TEMPERATURE ARE AS FOLLOWS

Density	0.289 [lb/in³]/ 8.02 [g/cm³]
Melting range	2,410 – 2,550 [°F]
Specific heat	0.11 [Btu/lb·°F]
Electrical resistivity	604 [ohm·circ mil/ft]/ 1.00 [μΩ·m]
Permeability at 200 oersted	1.004
Specific heat	0.11 [Btu/lb·°F]/ 454 [J/kg·°C)
Young´s modulus	27.7 [10^3 Ksi]/ 191.0 [GPa]
Thermal expansion at 200 °F	8.3 [in/in·°F x 10^{-6}]/ 15.03 [cm/cm·°C x 10^{-6}]

Alloy 27-7MO is also identified as UNS S31277. For comparison purposes, the 25-6MO alloy is identified as UNS N08926. A number of other commercially available alloy designations are related to alloy 25-6MO through the UNS N08926 designation or through published chemistry ranges. These alternate designations or trademarks include:

_ INCOLOY® alloy 25-6MO
(trademark of Special Metals Corporation)
_ GD31MO (trademark of Greening Donald)
_ SUPA 75 (trademark of Bridon)
_ Cronifer® 1925hMo (trademark of Krupp VDM)
_ AL6XN (trademark of Allegheny Ludlum Corporation)
_ Phy 4529
(trademark of Metalimphy Alloys Corporation)

Material produced to the UNS S31277 or UNS N08926 chemistry ranges and manufactured into armor wire or wirelines by Zapp Precision Wire will provide an excellent quality product. Zapp Precision Wire technology, quality, and superior wire drawing capabilities will make the difference for these critical applications.

The Zapp Precision Wire quality system is registered to ISO 9001:2008. For additional information on this or any other Zapp Precision Wire, Inc. product, please contact the Customer Service Department at 843-851-0700 or fax your inquiry to 843-851-0100, or e-mail the inquiry to sales@zapp.com.

ZAPP TECHNICAL DATA

ALLOY CHEMISTRY

Alloy	UNS	C	Mn	Cr	Ni	Mo	Cu	N	Co	Ti	Fe
316	S31600	.08	2.0	16.0 – 18.0	10.0 – 14.0	2.0 – 3.0.	-	-	-	-	bal.
2205	S32205	.03	2.0	21.0 – 23.0	4.5 – 6.5	2.5 – 3.5	-	.18	-	-	bal.
XM19	S20910	.06	4.0 - 6.0	20.5 – 23.5	11.5 – 13.5	1.5 – 3.0	-	.20 - .40	-	-	bal.
2507	S32750	.03	1.2	25.0	7.0	4.0	-	.30	-	-	bal.
25-6MO	NO8926	.02	2.0	19.0 – 21.0	24.0 - 26.0	6.0 – 7.0	.5 – 1.5	.15 - .25	-	-	bal.
27-7 MO	S31277	.02	3.0	20.5 – 23.0	26.0 – 28.0	6.6 – 8.0	.5 – 1.5	.30 - .40	-	-	bal.
MP35N®	R30035	.02	0.1	19.0 – 21.0	33.0 – 37.0	9.0 – 10.5	-	-	bal.	1.0	1.0
C276	N10276	.01	1.0	14.5 – 16.5	bal.	15.0 – 17.0	-	-	2.5	-	4.0 – 7.0

(Maximum values unless range specified)

ARMOR WIRE TYPICAL TENSILE STRENGTH RANGES (KSI)

Size	316	XM19	25-6MO	27-7MO	MP35N®
.020" - .029"	230/260	250/280	245/275	250/280	270/300
.030" - .066"	225/260	245/280	240/275	245/280	265/300

WIRELINE MINIMUM BREAK STRENGTH**

Size	316	2205	XM19	2507	25-6MO	27-7MO	MP35N®	C276
.082"	1150#	1345#	1215#	1345#	1175#	1300#	1300#	1280#
.092"	1500#	1690#	1540#	1690#	1500#	1650#	1690#	1615#
.108"	2000#	2240#	2000#	2240#	2130#	2250#	2300#	2210#
.125"	2700#	2945#	3000#	2975#	2750#	3000#	3100#	2935#
.140"	3300#	3540#	3540#	3694#	3250#	3670#	3725#	3680#
.150"	3750#	3975#	4065#	4150#	3750#	4155#	4240#	4205#
.160"	4225#	4425#	4325#	4665#	4250#	4650#	4825#	4785#

(** The recommended **safe working load** is 60% of minimum break strength)

DENSITY/CORROSION

Alloy	Density (lb/in^3)	Corrosion (PREN)*	CPT (°F)	CPT (°C)**
316	.287	26	72	22
2205	.278	36	108	42
XM19	.285	38	106	41
2507	.281	41	144	62
25-6MO	.290	47	149	65
27-7MO	.289	56	176	80
MP35N®	.309	53	183	84
C276	.321	68	>302	>150

* PREN = Cr + 3.3 Mo + 30N

** CPT (°C) = 2.5 Cr + 7.6 Mo + 31.9 N - 41

EXAMPLES OF THEORETICAL ACCEPTABLE WELL ENVIRONMENTS FOR 27-7MO WIRE*

Chlorides	Temp °F	H_2S	CO_2	Pressure (PSI)	Req. Minimum Pitting Index (PI)	27-7MO (PI)	27-7MO (PREN)
20,000 ppm	400	1 %	10 %	5,000	37.00	49.53	56
150,000 ppm	450	3 %	11 %	5,000	40.00	49.53	56
100,000 ppm	275	10 %	10 %	10,000	43.00	49.53	56
120,000 ppm	380	20 %	30 %	15,000	43.00	49.53	56
20,000 ppm	180	40 %	60 %	3,000	40.00	49.53	56
25,000 ppm	425	3 %	3 %	3,000	37.00	49.53	56

*The theoretical acceptable well environments are based on the SOCRATES software. SOCRATES is a comprehensive material selection tool for oil and gas applications that selects corrosion resistant alloys (CRA) through material evaluation based on mechanical strength parameters, heat treatment/cold work and hardness limitations. The program also evaluates the characterization of the environment in terms of operating pressure, temperature, pH, H_2S, chlorides, elemental sulfur, aeration, gas to oil ratio and water to gas ratio water cut. Stress corrosion cracking, hydrogen embrittlement cracking, sulfide stress cracking and resistance to pitting corrosion are also evaluated. The examples above are based on the environment listed and do not take into consideration the actual values of elemental sulfur, aeration, gas to oil ratio and water to gas ratio water cut.

NOTE: The information in the Socrates summary report does not represent a commitment by Honeywell InterCorr International or Zapp Precision Wire, Inc. The information contained in this document and the Socrates software is purely advisory in nature. In no event shall Honeywell InterCorr, Zapp Precision Wire, Inc., or their employees or agents have liability for damages, including but not limited to, consequential damages arising out of or in connection with any person's use or inability to use the information in this document.

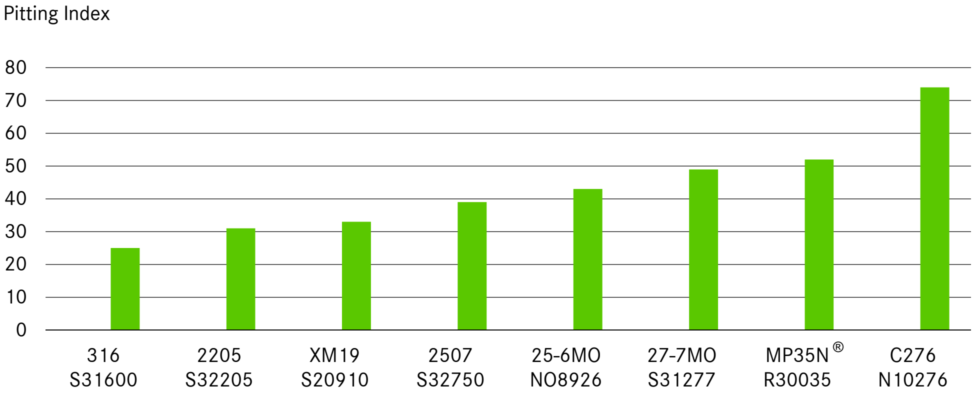
PI = Cr + 3.3Mo +11N +1.5(W+Nb)

PREN = Cr + 3.3Mo + 30N

NOMINAL CHEMICAL COMPOSITION COMPARISON

Chemical Element	316	2205	XM19	2507	25-6MO	27-7MO	MP35N®	C276
Fe	65.40	67.71	56.40	62.43	46.30	39.65	1.00	5.5
Mn	2.00	2.0	5.00	0.6	2.00	3.00	0.15	0.5
Ni	12.00	5.5	12.50	7.0	25.00	27.00	35.00	55.0 bal.
Co	*	*	*	*	*	*	32.90	2.0
Cr	17.00	22.0	22.00	25.0	20.00	21.75	20.00	15.5
Mo	2.50	2.5	2.25	4.0	6.50	7.25	9.75	16.0
W	*	*	*	*	*	*	*	*
Nb	*	*	0.20	*	*	*	*	*
N	*	0.12	0.30	*	0.20	0.35	*	*
*Trace								
PI	25.25	31.57	33.03	39.85	43.65	49.53	52.18	74.43

MATERIAL SELECTION OVERVIEW



WEIGHT PER FOOT (LBS.) FOR WIRELINES

Alloy	.082"	.092"	.108"	.125"	.140"	.150"	.160"
316	0.018	0.023	0.031	0.042	0.053	0.060	0.069
2205	0.018	0.022	0.031	0.041	0.052	0.059	0.068
XM19	0.018	0.023	0.031	0.042	0.053	0.060	0.069
2507	0.018	0.022	0.031	0.041	0.052	0.059	0.068
25-6MO	0.018	0.023	0.032	0.043	0.054	0.062	0.070
27-7MO	0.018	0.023	0.032	0.043	0.054	0.062	0.070
MP35N®	0.020	0.025	0.034	0.046	0.057	0.066	0.075
C276	0.018	0.022	0.031	0.041	0.052	0.059	0.068

ZAPP PRECISION WIRE STANDARDS

1. All wirelines must pass an eddy current test as part of our NDT quality assurance program.
2. All wirelines and armor wires must pass an aged wrap test as part of our ductility quality assurance program.
3. All wirelines and armor wires have full traceability.
4. All 27-7MO wirelines and armor wires are produced using shaved, defect free rod material.

ZAPP PRECISION WIRE QUALITY

The Zapp Precision Wire technology, quality, and superior wire drawing capabilities will make the difference for critical armor wire and wireline applications.
The Zapp Precision Wire quality system is registered to ISO 9001:2015.

ZAPP PRECISION WIRE
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