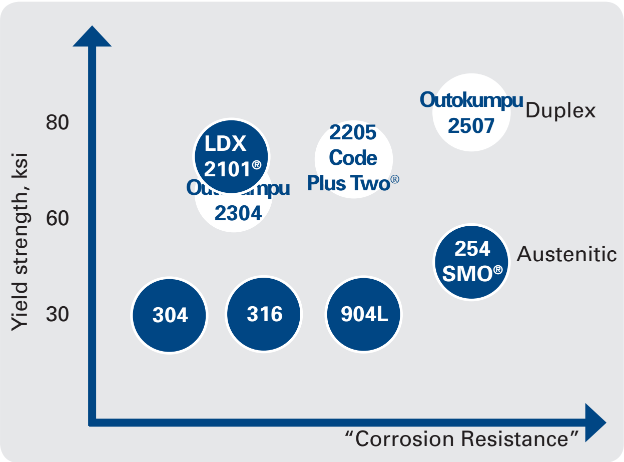
outokumpu
high performance stainless steel

North American Version
Imperial Units

LDX 2101® Comparative for Flat Rolled Products

LDX 2101® Summary/Overview

Outokumpu	EN	UNS
LDX 2101®	1.4162	S32101



Characteristic properties
High strength
Good fatigue resistance
Good corrosion resistance
High resistance to stress corrosion cracking
High energy absorption
Very good machinability

Applications
General-purpose applications and environments
Buildings, bridges, and storage construction
Storage tanks
Flood-gates
Water treatment
Pulp and paper equipment
Architectural wall panels and structural members
Road tanks
Dimpled jackets

General Characteristics
LDX 2101® is a low-alloyed, general purpose duplex stainless steel. Its high mechanical strength is similar to that of other duplex grades and its good corrosion resistance is on par with that of most standard stainless steel grades. Combined, these properties can be utilized to arrive at a design optimized with respect to strength, maintenance, durability and long-term cost efficiency.

Chemical characteristics
The chemical composition is shown in Table 1.

Microstructure
The balanced chemical composition of LDX 2101 results in a microstructure containing approximately equal amounts of ferrite and austenite after annealing at a temperature of about 1920°F/1050°C. Due to its relatively low alloying content, LDX 2101 is less prone to precipitation of intermetallic phases than other duplex steels. The high nitrogen content results in rapid re-formation of austenite in weld thermal cycles.

Table 1

Steel	Typical composition, %							Microstructure
Grade	Cr	Ni	Mo	C	N	MN	PREN	
304	18.1	8.3	—	0.04	—	—	18	Austenitic
316	17.2	10.2	2.1	0.04	—	—	24	Austenitic
LDX 2101®	**21.5**	**1.5**	**0.3**	**0.03**	**0.22**	**5**	**26**	**Lean Duplex**
Outokumpu 2304	23	4.8	0.3	0.02	0.10	—	26	Lean Duplex
2205 Code Plus Two®	22	5.7	3.1	0.02	0.17	—	35	Duplex
Outokumpu 2507	25	7	4	0.02	0.27	—	42	Super Duplex

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

Mechanical Properties

LDX 2101 has high mechanical strength due to its duplex microstructure and high nitrogen content. In Table 2 the minimum values for the grades are presented.

Materials - Mechanical Properties — Table 2

Steel Grade ASTM		ASTM, min values Yield, ksi	Tensile, ksi	Elongation [%]
304L		30	75	40
316L		25	70	40
LDX 2101®	≥3/16”	65	94	30
	<3/16”	77	101	—
Outokumpu 2304		58	87	25
2205 Code Plus Two®		65	95	25
Outokumpu 2507		80	116	15

Fatigue, pulsative test — Table 3

Minimum value	LDX 2101®		2205 Code Plus Two®		316L	
	MPa	KSI	MPa	KSI	MPa	KSI
Yield Strength 0.2%	478	69	497	72	280	40
Tensile Strength	696	100	767	111	578	83
Fatigue Strength	500	72	510	73	360	52

Standard deviation of fatigue strength, for the entire population ~ 30 MPa/5 KSI

Fatigue

The high tensile strength of duplex steels also implies high fatigue strength. Table 3 shows the result of pulsating tensile fatigue tests (R=0.1) in air at room temperature. The fatigue strength has been evaluated at 2 million cycles and probability of rupture is 50%. Since the test was made using round polished test bars from hot rolled plate, correction factors for surface roughness, notches, welds, etc, are required in accordance with classical theory relating to fatigue failure. As shown by the table, the fatigue strength of the duplex steels corresponds approximately to the yield strength of the material.

Corrosion Resistance

The corrosion resistance of LDX 2101 is generally good, and the grade is therefore suitable for use in a wide range of general-purpose applications and environments. The corrosion resistance is in general at least as good as that of Cr-Ni grades such as 304 and in most cases as good as Cr-Ni-Mo grades such as 316L. A brief description of the resistance to different types of corrosion is described below.

Uniform corrosion

Uniform corrosion is characterized by a uniform attack on the steel surface in contact with a corrosive medium. The corrosion resistance is generally considered good if the corrosion rate is less than 0.1 mm/year. See Table 4.
LDX 2101 has a better resistance than 304 and in most cases performs as well as 316L with 2.5 min Mo. One exception is sulfuric acid, as shown in Figure 1.

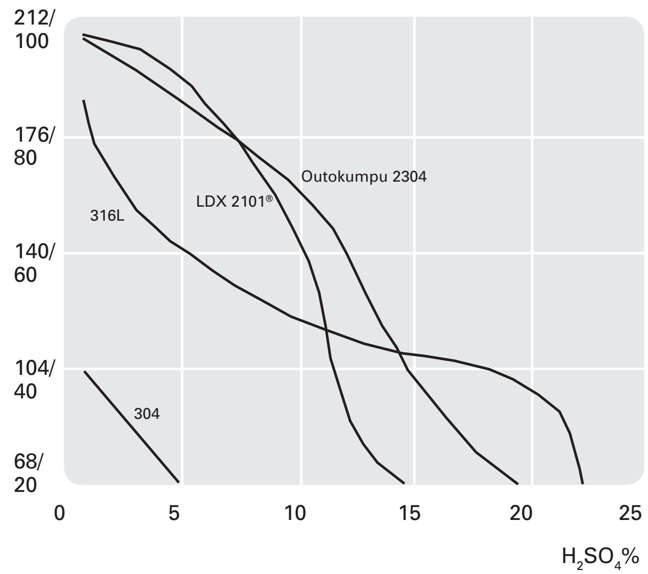


Fig. 1 Isocorrosion curves, 0.1 mm/year, in sulphuric acid

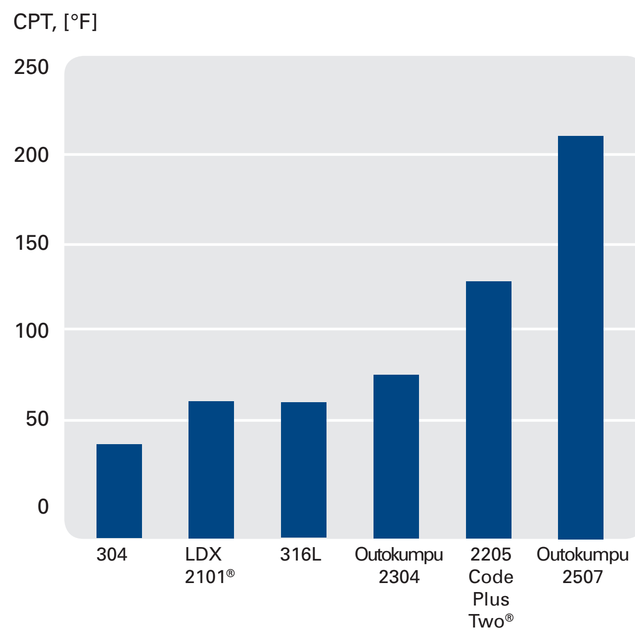


Fig. 2 Typical CPT values in 1M NaCl for tested stainless steels tested in ground conditions according to ASTM G150.

Pitting and crevice corrosion

The resistance to pitting and crevice corrosion increases with the content of chromium, molybdenum and nitrogen in the steel. The resistance to these types of corrosion, which are mainly caused by chloride containing environments, is good due to the grade’s high chromium and nitrogen content. The pitting corrosion resistance has been evaluated using the Avesta Cell (ASTM G 150). Figure 2 shows that the resistance is higher than that normally obtained with Cr-Ni grades such as 304 and approaching that of Cr-Ni-Mo grades such as 316L.

Uniform Corrosion Results — Table 4

Test solution	Conc, wt%	Critical temperature ˚F (˚C) 316L	304	S32101
Hydrochloric Acid				
HCl	0.2	>bp	>bp	>bp
HCl	1.0	86(30)	86(30)p	140(55)
HCl+$FeCl_3$	1.0HCl + 0.3$FECl_3$	25p	20p	20
Sulfuric Acid				
H_2SO_4	10	122(50)	N.T.	167(75)
	60	<59(<15)	N.T.	<86(<30)
	96.4	113(45)	N.T.	86(30)
Phosphoric Acid				
H_3PO_4	85	203(95)	176(80)	214(100)
Nitric Acid				
HNO_3	10	>bp	>bp	>bp
	65	214(100)	214(100)	221(105)
Organic Acids				
Acetic acid CH_3COOH	80	>bp	214(100)	>bp
Acetic acid+ acetic anihydride CH3COOH+ $(CH_3CO)_2O$	50+50	248(120)	<bp	221(105)
Formic acid HCOOH	50	104(40)	<50(<10)	203(95)
Sodium Hydroxide				
NaOH	50	194(90)	185(85)	185(85)

N.T.= Not Tested *bp.= Boiling Point* *p.= Pitting Corrosion*

For further information concerning corrosion in other media, contact your local Outokumpu Sales Representative.

Atmospheric corrosion
A steel's resistance to atmospheric corrosion is strongly linked to its resistance to uniform corrosion and localized corrosion such as pitting and crevice corrosion. Since LDX 2101 shows good resistance to these types of corrosion, it may be assumed that the resistance to atmospheric corrosion is good. Accordingly LDX 2101 should be sufficiently resistant in most environments.

Stress corrosion cracking
Like all duplex steels, LDX 2101 shows good resistance to chloride-induced stress corrosion cracking (SCC). Many test methods are used to rank the different steel grades with respect to their resistance to SCC. One such test method is the U-bend test according to MTI Manual no. 3, in which the specimens are exposed to 3M magnesium chloride (MgCl2) solution at 100° C for 500 hours. The U-bending was performed both longitudinal and transverse to the rolling direction. The results are shown in Table 5.

Results from U-bend stress corrosion testing in $MgCl_2$ — Table 5

	Longitudinal/Transverse
LDX 2101®	No SCC (some uniform corrosion)
Outokumpu 2304	No SCC (some uniform corrosion)
304	SCC cracks + pitting corrosion

Summary of Test Results for the Wick Test — Table 6

Material UNS No.	Number of Specimens: Tested	Failed due to SCC
S30400	2	2
S32101	6	0
S32304	2	0
S32205	2	0

Summary of Test Results for Concentrated Calcium Chloride — Table 7

Material UNS No.	Exposure time [h]	Number of Specimens			
		U-bend		4-PB	
		Tested	Failed due to SCC	Tested	Failed due to SCC
S30400	96	6	6	—	—
	340	—	—	4	4
S32101	500	6	0	2	0
S32304	500	6	0	2	0
S32205	500	6	0	2	0
S32750	500	—	—	2	0

Intergranular corrosion
Due to its duplex microstructure LDX 2101 offers very good resistance to intergranular corrosion. Duplex stainless steels are less susceptible to this kind of corrosion than austenitic steels.

Fabrication
Hot Forming
Hot forming is performed in the temperature range 2000-1650° F/1100-900° C and should be followed by solution annealing. It should, however, be observed that the strength is low at high temperatures.

Cold Forming
Due to the high proof strength of duplex material, greater working forces than those required for austenitic steel are usually needed for cold forming. Figure 3 shows the effect of work hardening on LDX 2101.

LDX 2101 is suitable for most forming operations used in stainless steel fabrication. However, due to the grade's higher mechanical strength and lower toughness, operations such as deep drawing, stretch forming and spinning are more difficult to perform than with austenitic steel. The grade's high strength, may give rise to a relatively high spring back.

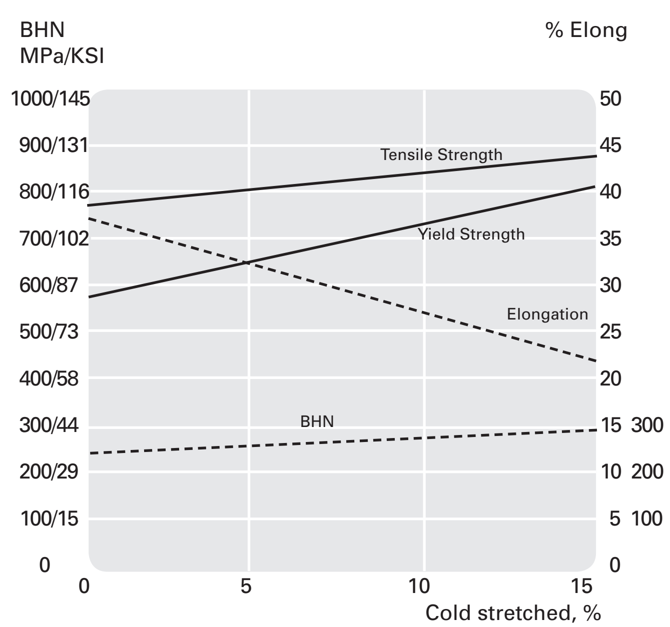


Fig. 3 Mechanical properties of LDX 2101® after cold deformation.

Heat treatment
LDX 2101 is solution annealed at 1870-1970° F/ 1020°-1080° C. Rapid cooling is recommended after annealing.

Machining
LDX 2101 has shown excellent machining properties in contrast to other duplex steels. Duplex steels are generally more difficult to machine than conventional austenitic stainless steel such as 316L 2.5 min Mo, due to the higher hardness.

Welding
Welders who are experienced in austenitic stainless steels, such as 304 and 316L, are aware of the need for low heat input to prevent hot cracking of the weld. Hot cracking is avoided by minimizing heat input and, where possible, using a filler metal that will form a significant volume fraction of ferrite. To achieve low heat input an austenitic material may be welded by a series of small passes, i.e., the use of stringer beads with minimal weave. As long as the austenitic stainless steel is low in carbon, or stabilized with titanium, there is little likelihood of any problems occurring in the HAZ of an austenitic stainless steel.

The problems encountered with duplex stainless steels are completely different. The duplex filler metals have a large volume of ferrite, so hot cracking of the weld metal is rare. Instead, the problems with duplex stainless steel relate to embrittlement of the HAZ either by too much ferrite or by formation of intermetallic phases. Intermetallic phases form due to being at higher temperature for too long a time. Because the time at temperature is a cumulative effect, it does not help for the welder of a duplex stainless steel to make many small passes as with a difficult austenitic material. In fact, it is often far better to make a duplex weld with a higher heat input procedure, provided that a larger weld deposition rate will enable a lower total time at temperature for the HAZ for the whole welding procedure.

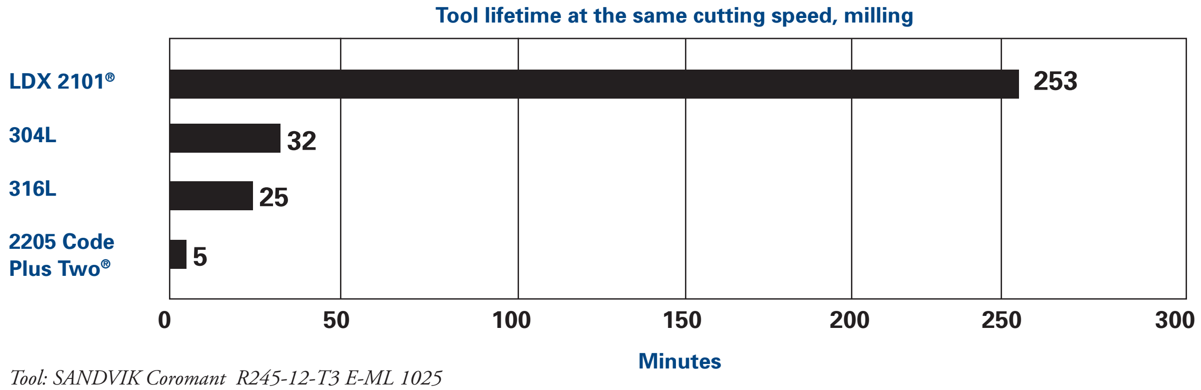
The interpass temperature should be as low as necessary to help keep the total time at temperature for a particular weld below the range where precipitation of carbides and sigma phase may occur. The limit on interpass temperature can be higher for LDX 2101 because it takes significantly longer to form intermetallic phases than for 2205 Code Plus Two®. To keep the total time at temperature short, stress relief heat treatment after welding is not recommended. Qualify a welding procedure by demonstrating that the procedure when applied to the base material at the proposed size will not lead to significant loss of toughness or corrosion resistance.

Product specification and approvals
LDX 2101 is standardized by ASTM/ASME. It has an EN number and work is in progress to obtain EN standardization for flat, bar and tubular products. Outokumpu has received a patent for LDX 2101.

Table 8

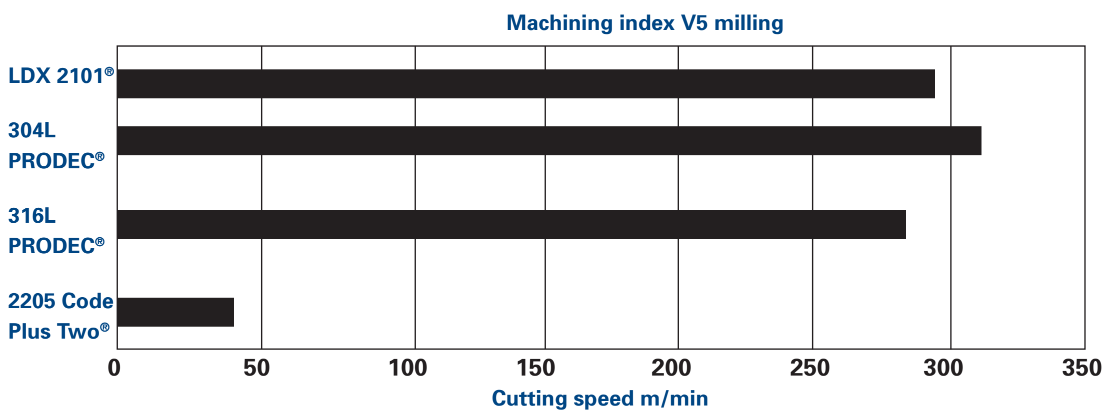
Welding LDX 2101® to	Preferred filler	Possible Filler	Third Choice
LDX 2101®	LDX 2101	2209 for slightly enhanced corrosion resistance	309L, 312
2205 Code Plus Two®	2209	LDX 2101	
Outokumpu 2507	2209	P100 for higher strength	
304	2209	309 gives slightly lower corrosion resistance and reduced strength	
316	2209	309 gives slightly lower corrosion resistance and reduced strength	316
C-Mn	2209 for better corrosion resistance	309 for higher strength	

Tool lifetime at 115m/min (350sfm), milling — Table 9



Tool: SANDVIK Coromant R245-12-T3 E-ML 1025

Machining Results from Milling (V5) in Outokumpu steel grades — Table 10



Tool: Vaporized HSS-Co tap, NORIS-SALO-REX-VA HSSE C
Prodec is a registered Outokumpu trademark for steel grades with improved machinability.

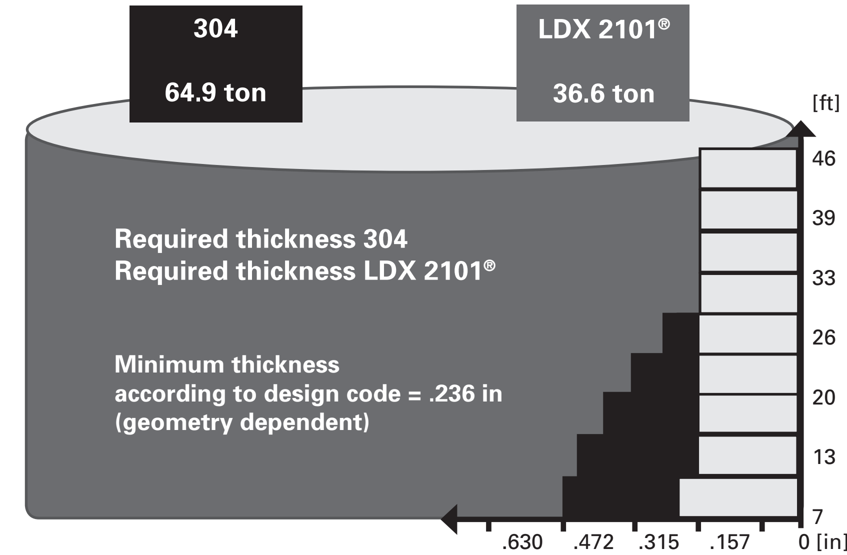
Products — Table 11

Hot rolled plate, sheet and strip	Dimensions according to Outokumpu product program.
Cold rolled sheet and strip	Dimensions according to Outokumpu product program.
Billet, wire rod and bar	Dimensions according to Outokumpu product program.
Pipe	Dimensions according to Outokumpu product program.
Welding consumables	Filler material in the form of covered electrodes of AC/DC type, MIG, TIG, FCW and SAW wire and also welding flux are supplied by Avesta Welding AB, Avesta

Material Standards — Table 12

ASTM A240/ASME SA-240	Heat-resisting Cr and Cr-Ni stainless steel plate/sheet/strip for pressure purposes
ASTM A276	Stainless and heat-resisting steel bars/shapes
ASTM A479/ASME SA-479	Stainless steel bars for boilers and other pressure vessels
ASME Boiler and Pressure Vessel Code Case 2418-1	21 Cr-5Mn-1.5Ni-N (UNS S32101), Austenitic-Ferritic Duplex Stainless Steel Section VIII, Division 1

LDX 2101®, Cost Advantage — Tank — Table 13



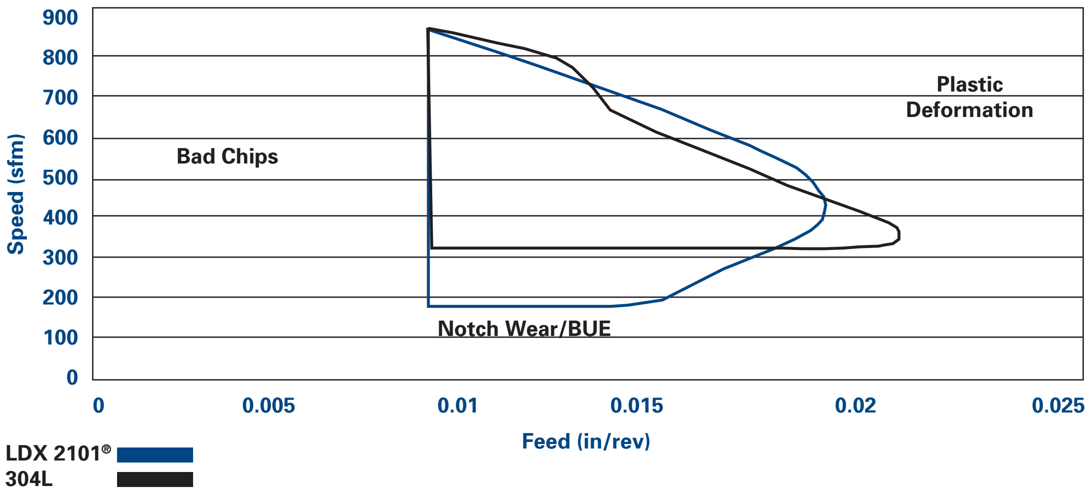
LDX 2101® Machining Guide — Table 14

Operation	Depth of cut or width (in)	HSS Tooling Cutting Speed (SFM)	HSS Tooling Feed (IPR)	HSS Tooling Tool Grade	Carbide Tooling Cutting Speed (SFM)	Carbide Tooling Feed (IPR)	Carbide Tooling Tool Grade
Turning	0.04-0.15	45-120	0.001-0.006	T15	80-700	0.0025-0.012	P15-M25
Forming	0.200	45-120	0.0005-0.006	T15	80-813	0.0005-0.010	P15-M25
Cut-off or Grooving	0.04-0.15	Up to 120	0.001-0.005	T15	80-360	0.001-0.008	M25
Drilling	All	40-120	0.003-0.009	M35	80-810	0.0025-0.012	P15-M25
Reaming	All	40-120	0.003-0.025	M35	80-810	0.0025-0.012	P15-M25
Taping	All	Up to 120	N/A	M35	—	—	—
Single Point Threading	—	—	—	—	114-490	Thread Size: 3/4"-10 Passes: 9-11	M20

- *Small differences in cutting speed will affect tool lifetime*
- *Higher feed rate tends to give better surface and chip formation*
- *TiAIN coated high speed steel tools provide much longer tool lifetime than un-coated*
- *Results can vary depending upon tooling and machine set-up*
- *These are actual results obtained from production tests*

Machining Window LDX 2101® vs. 304L

Table 15



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