Titre: Title:	Microstructural and fatigue characterization of 316L stainless steel subjected to flow drilling and tapping: comparison with machined threads. Supplément
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Date:	2024
Type:	Article de revue / Article
Référence: Citation:	Mechter, M. A., Gadour, M., Romain, L., Tuysuz, O., & Brochu, M. (2024). Microstructural and fatigue characterization of 316L stainless steel subjected to flow drilling and tapping: comparison with machined threads. Engineering Failure Analysis, 164, 108730 (13 pages). https://doi.org/10.1016/j.engfailanal.2024.108730

Titre de la revue: Journal Title:	Engineering Failure Analysis (vol. 164)
Maison d'édition: Publisher:	Elsevier
URL officiel: Official URL:	https://doi.org/10.1016/j.engfailanal.2024.108730
Mention légale: Legal notice:	

Supplementary Information for: Microstructural and fatigue characterization of 316L stainless steel subjected to flow drilling and tapping: comparison with machined threads.

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S1. Hardness Measurements

Figure 1 shows how a specimen is cut to perform hardness measurements on holes 1 and 4 to determine if a series of drilling and tapping operations affects the hardness of the material. Tables 2 and 3 present the raw hardness data for the first and fourth cutting threads respectively. It can be observed that the hardness measured in the first hole is similar to the one in last hole. Tables 4 and 5 present the raw hardness data for the first and fourth flow processed threads. No difference is noted between the first and the last hole.

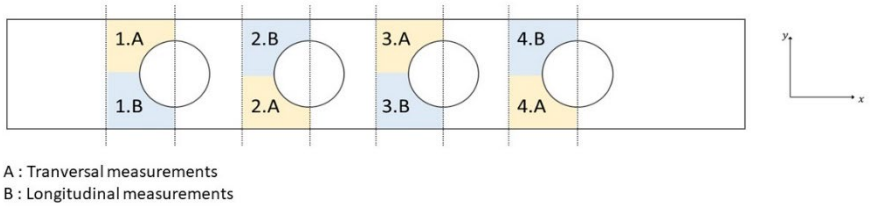

Figure 1. Cutting samples for hardness measurement from the threaded specimens

Table 1. Hardness measurements of conventional specimen, sample 1.A and 1.B

	1.A			1.B	
	Distance from the thread root (µm)	**Hardness HV**		**Distance from the thread root (µm)**	**Hardness HV**
	372,65	190		393,55	187
	797,56	185		803,31	181
	1177,53	178		1163,41	167
	1115,33	174		1566,37	166
	1356,27	175		2044,04	152
	1571,08	174		2375,92	158
	1809,93	174		2792,47	158
	2048,78	171		3233,58	157
	2284,49	169		3648,04	168
	2523,86	172		4063,55	157
	2802,95	168		4485,33	159
	3048,07	170		4870,00	163
	3282,74	181		5272,96	161
	3522,64	195		5662,86	165
	3760,44	181		6081,50	162
	4039,01	245		6472,44	168
	3926,64	227		6862,86	161
	3922,46	233		7265,82	153
	4290,40	266		7669,83	158
	4526,11	304		8061,29	159
	4759,21	333		8465,30	159
	4866,84	350		8856,76	154
	9,22	519		9260,24	162
	53,40	294		508,02	165
	120,55	285		796,00	165
Close to the surface (measurements using 25 g mass)	203,14	239	*Close to the surface (measurements using 25 g mass)*	1098,61	171
	294,37	243		1387,63	169
	324,08	239		9,22	519
	414,53	226		78,14	291
				150,00	236
				83,9	282
				178,14	234
				280,37	230
				364,79	222
				489,27	220

Table 2 Hardness measurements of conventional specimen, sample 4.A and 4.B

	4.A	
	Distance from the thread root (µm)	**Hardness HV**
Close to the surface (measurements using 25 g mass)	233,62	210
	451,56	184
	654,87	174
	894,92	171
	1152,59	187
	1402,94	164
	1617,23	165
	1864,44	167
	2118,97	169
	2347,37	170
	2613,4	166
	2848,59	169
	3055,04	177
	3294,41	186
	3537,44	210
	3778,90	237
	4024,02	263
	4006,25	267
	4257,12	294
	4480,29	318
	4780,26	345
	3907,99	247
	3666,53	232
	9,22	519
	62,43	303
	134,55	291
	213,74	250
	295,28	230
	338,34	232
	411,51	226
	509,55	224

	4.B	
	Distance from the thread root (µm)	**Hardness HV**
Close to the surface (measurements using 25 g mass)	230,49	199
	459,41	175
	689,90	166
	914,64	169
	1180,67	161
	1416,38	165
	1664,64	164
	1910,81	168
	2163,35	152
	2390,70	154
	2646,27	160
	2892,44	167
	3131,29	156
	3386,86	168
	3636,16	155
	3887,55	160
	4148,36	161
	4392,44	159
	4650,11	160
	4941,22	157
	5181,52	155
	5424,55	157
	5730,30	167
	5973,33	168
	6237,27	164
	6463,58	162
	6710,79	160
	6962,18	161
	7210,64	156
	7470,40	162
	7717,61	159
	7981,55	160
	8253,85	161
	8497,93	164
	9,22	519
	67,15	306
	157,6	245
	197,26	230
	220,43	226
	315,06	216
	461,26	212
	424,61	206

Table 3 Hardness measurements of flow processed specimen, sample 1.A and 1.B

	1.A	
	Distance from the thread root (µm)	**Hardness HV**
Close to the surface (measurements using 25 g mass)	408,19	246
	796,52	230
	1255,93	211
	1035,37	211
	1667,25	201
	2011,68	196
	2390,6	196
	2684,85	226
	3021,96	220
	3389,38	249
	3699,31	275
	4033,80	320
	10,62	759
	49,74	393
	102,75	342
	152,23	303
	267,28	316
	333,12	294
	407,20	273
	461,52	276

	1.B	
	Distance from the thread root (µm)	**Hardness HV**
Close to the surface (measurements using 25 g mass)	270,73	281
	602,61	258
	959,58	243
	1243,38	267
	1622,30	241
	1924,91	222
	2267,77	185
	2540,07	192
	2910,63	182
	3282,76	178
	3627,19	191
	3980,71	191
	4353,36	181
	4738,55	183
	10,62	759
	56,15	388
	143,98	338
	230,50	342
	276,7	316
	363,74	291
	443,98	265
	494,90	303

Table 4 Hardness measurements of flow processed specimen, sample 4.A and 4.B

	4.A			4.B	
	Distance from the thread root (µm)	Hardness HV		Distance from the thread root (µm)	Hardness HV
Close to the surface (measurements using 25 g mass)	311	270	Close to the surface (measurements using 25 g mass)	240,42	282
	521	252		511,67	240
	741	250		765,15	251
	845	236		1025,95	242
	1077	229		1285,71	232
	1323	217		1533,97	219
	1572	201		1811,4	209
	1800	196		2076,38	181
	2045	197		2348,68	179
	2349	202		2617,84	182
	2611	201		2879,69	174
	2825	208		3134,22	178
	3077	212		3410,7	180
	3339	236		3680,91	182
	3598	250		3974,12	182
	3863	283		4228,65	173
	4174	325		4498,86	178
	10,62	759		4743,98	181
	55,89	384		10,62	759
	132,72	347		63,22	384
	156,41	330		153,67	327
	232,46	273		239,93	297
	374,21	265		332,47	291
	452,09	282		383,91	265
	102,88	330		465,98	250

S2. Fatigue Tests Raw data

Table 5 shows the raw data from the fatigue tests conducted during this study. It is noted that 6 F specimens were tested with a maximum loading level of 700 N. It should be reminded that the tests were run at a stress ratio of 0.1 and the run-out is set at 10^7 cycles.

Table 5. Fatigue test raw data

Load Max (N)	Maximum bending moment (N.m)	Number of cycle	
		C	F
1125	16,875	1,03E+05	1,14E+05
		1,75E+05	1,01E+05
		1,35E+05	1,12E+05
		3,52E+05	1,68E+05
		1,69E+05	1,12E+05
900	13,5	3,70E+05	2,55E+05
		3,90E+05	1,73E+05
		3,98E+05	4,94E+05
		4,59E+05	3,29E+05
		3,58E+05	7,96E+05
700	11,25	1,00E+07	1,00E+07
		1,00E+07	4,93E+05
		9,07E+05	7,04E+05
		1,04E+06	2,21E+05
		1,00E+07	2,63E+05
			7,63E+05

S3. Material analysis

The following figures present an analysis conducted using an SEM on samples from a test specimen related to the project that have not undergone any testing. The samples were polished up to the OPS stage to reveal the microstructure at the thread's root (Figure 2), crest (Figure 3), and in the bulk material (Figure 4) where the influence of flow drilling and flow tapping is no longer present. These microstructure images are accompanied by EDS analyses performed in the three mentioned zones. The chemical composition does not vary across the sample. The microstructure near the surface of the threads (both crest and root) is very fine owing to : the work hardening induced by flow drilling and flow tapping, the heating of the material during flow drilling and the air cooling. The grain orientation induced by the material flow during flow drilling and flow tapping is also visible at the root and crest of the thread. As shown by the Figure 5, the increase in hardness observed is consistent with the reduction of the grain size.

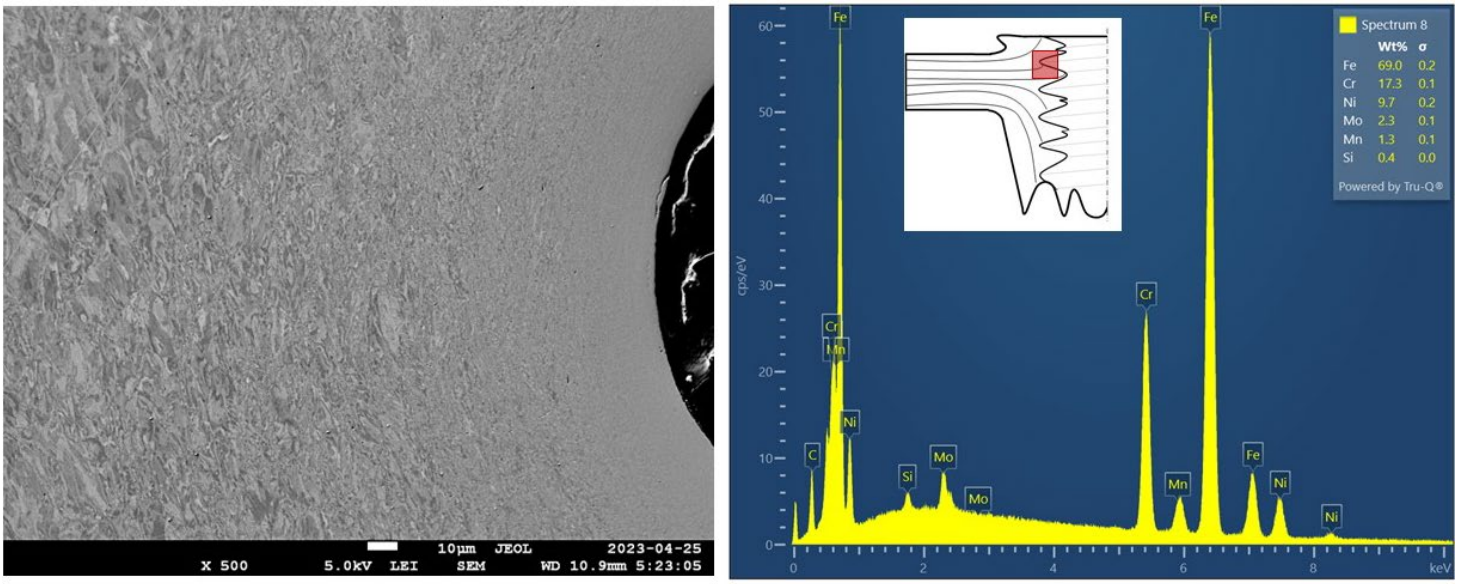

Figure 2. Microstructure and EDS analysis at the thread's root

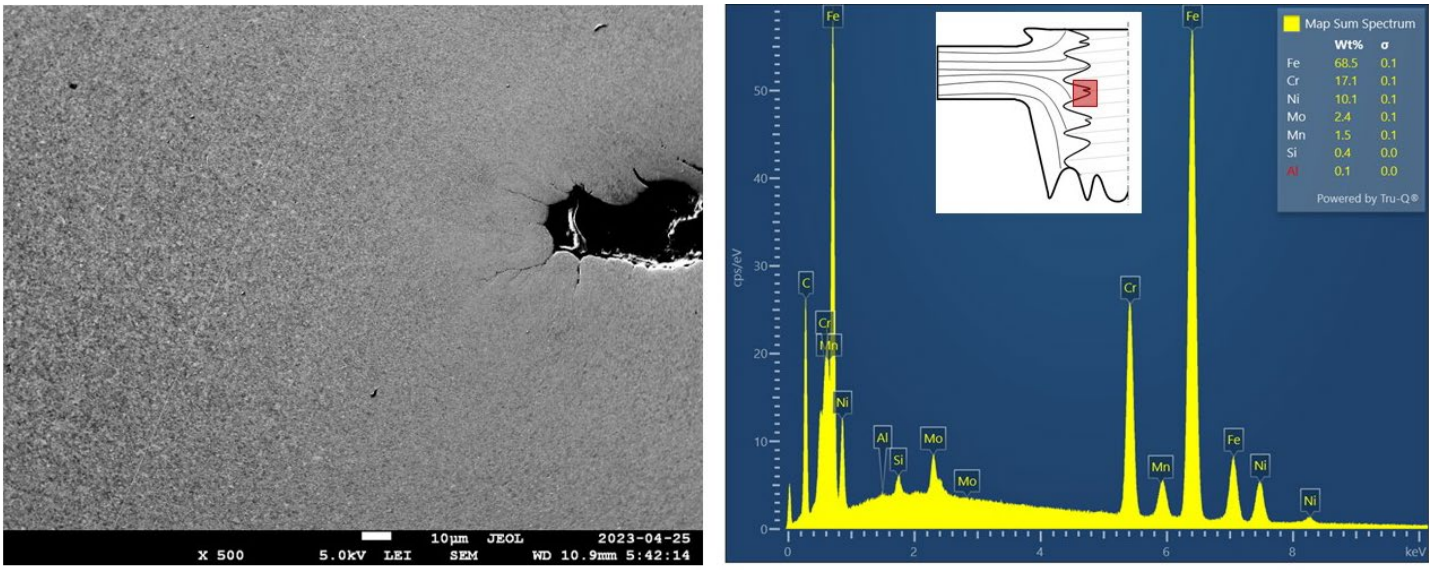

Figure 3. Microstructure and EDS analysis at the thread's crest

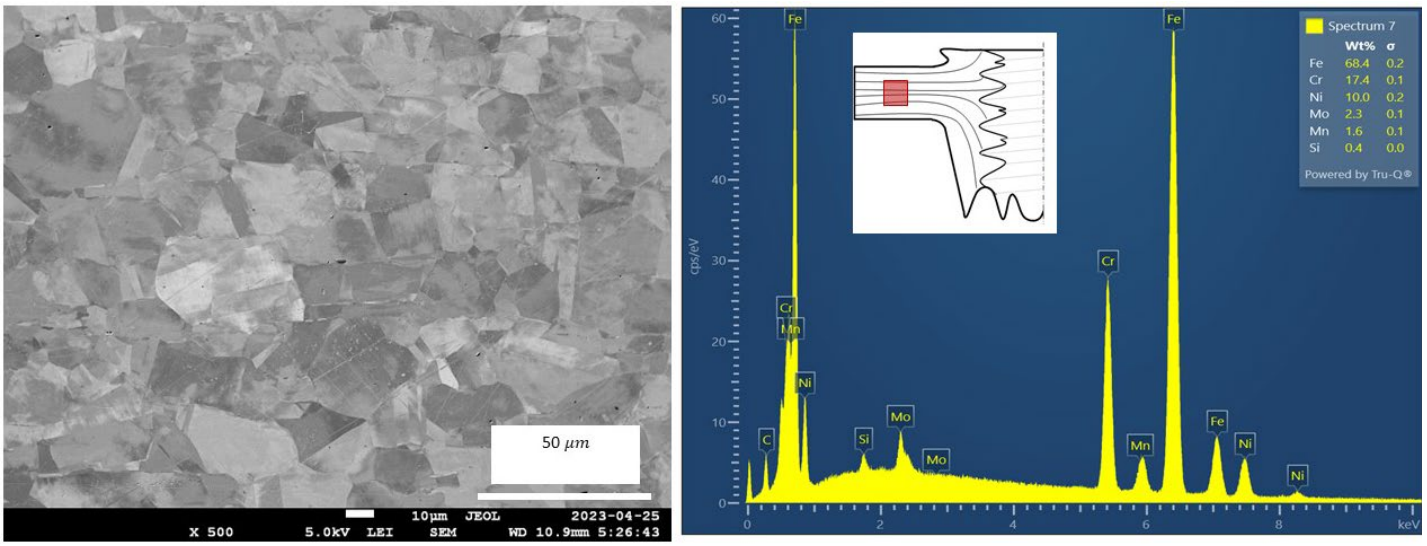

Figure 4. Microstructure and EDS analysis of the bulk material

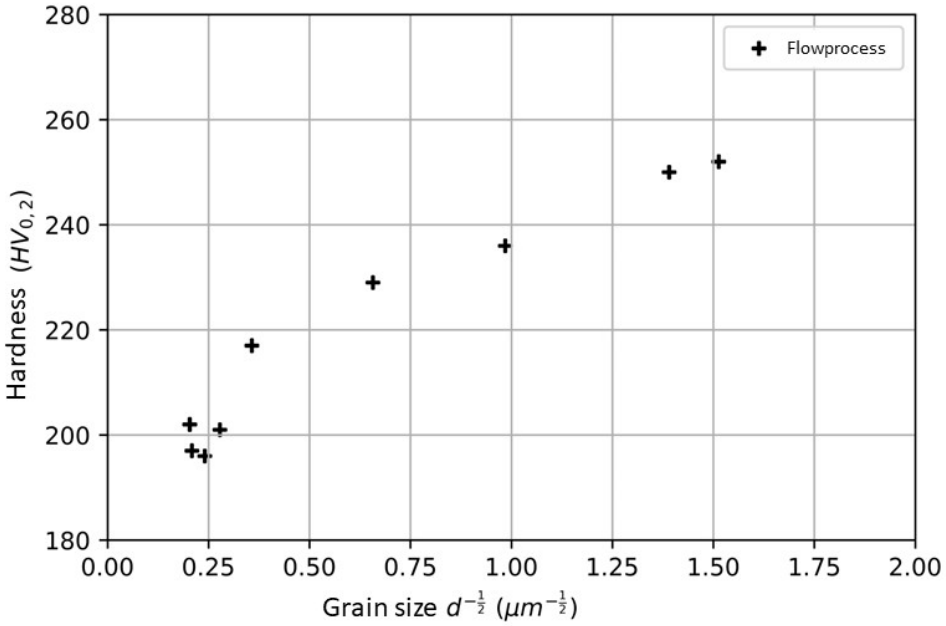

Figure 5. Hardness measurement related to grain size

S4. Evolution of the temperature during a flow drilling sequence

The flow-drilling tool was instrumented with a thermocouple placed at its center. The temperature was measured during a drilling operation. Figure 6 shows the temperature reached by 316L during a flow-drilling operation with the operating parameters used during this study. As can be seen, the material does not reach its melting temperature; at most, it reached 85% of its melting temperature.

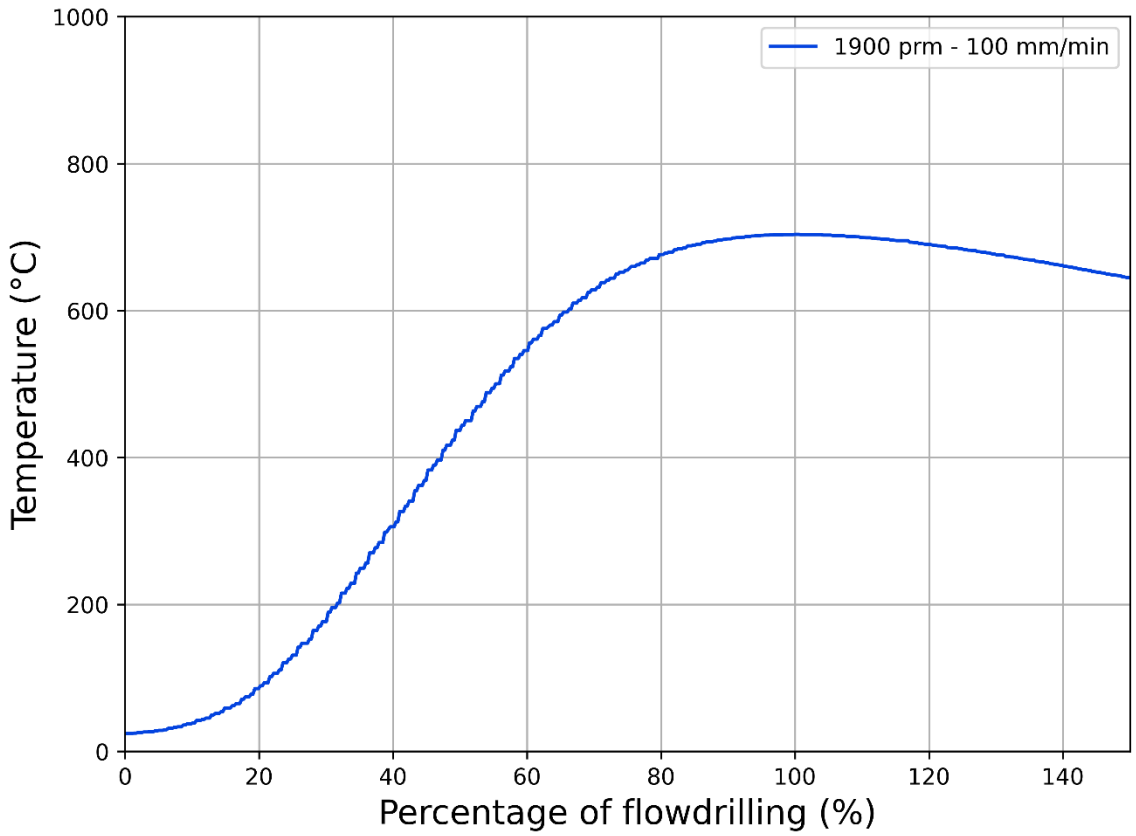

Figure 6. Evolution of the temperature at the tip of the flow drilling tool during a flow drilling sequence