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Progress Report

A COMPARATIVE EVALUATION OF A MODIFIED MEDIUM, CARBON GRADE, FREE-MACHINING STEEL AND TWO SIMILAR STANDARD GRADES

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ABSTRACT

This investigation, initiated by the Bethlehem Steel Company, was a comparative study of the turning qualities of a modified analysis C1144 and two standard grades with very similar properties, C1144 and C1141. Chip formation, tool life, and surface finish were the machinability criteria for the evaluation.

Viewing the results of this investigation as a whole, the standard and the modified C1144 steels are both rated higher than the C1141 in all machinability criteria. The differences between the two C1144 steels, however, did not show any consistent trend in favor of either. The relative behaviors are sensitive to cutting conditions, cutting time, evaluation techniques, and interpretation. Differences in chip formation and surface finish are erratic and are of more academic than practical significance. On the other hand, tool-life results warrant more consideration, for the materials go through a complete reversal of tool-life behavior. The standard C1144 holds an edge with high-speed steel cutting tools, particularly at lower rates. With carbide cutting tools, however, the modified C1144 steel can run as much as 50% faster with comparable tool wear and surface-finish results.

INTRODUCTION

The bulk of the work material used in this investigation was in the hot-rolled condition. A very small sampling of cold-drawn bars of each grade was also made available. The chemical analyses and properties of these materials, as furnished by the Bethlehem Steel Company, are listed in Table I.

TABLE I

TEST MATERIAL COMPOSITION AND PROPERTIES*

Grade	% Composition				
	C	Mn	P	S	Si
C1144	0.43	1.50	0.016	0.31	0.22
C1144 modified	0.45	1.22	0.015	0.20	0.13
C1141	0.41	1.43	0.017	0.11	0.08

Bar Diameter, in.	Grade and Condition	Mechanical Properties				
		Y.S.,** psi	T.S., psi	El.,*** %	R.A., %	BHN
	C1144					
3-7/16	H.R.	52,500	98,400	19.0	35.0	201
3-3/8	C.D.	98,600	107,000	14.5	38.4	217
	C1144 Modified					
3-1/2	H.R.	50,200	96,300	21.5	41.9	201
3-7/16	C.D.	99,500	108,100	15.5	36.6	223
	C1141					
3-9/16	H.R.	50,500	98,100	19.0	37.8	201
3-1/2	C.D.	98,300	105,400	14.5	42.3	217

*Supplied by Bethlehem Steel Company.

**0.2% offset.

***2-in. gage length.

The test program was limited to conventional turning with high-speed steel (HSS) and carbide cutting tools at what were considered to be representative cutting conditions. All tests were conducted dry on a 15 hp, 14x30 American "Pacemaker" lathe equipped with a variable speed drive and capable of a top speed of 2000 rpm. The HSS tools were standard 1/2 in. square tool bits of a single grade, Latrobe's "Electrite No. 1," a T-1 high-speed steel.

The carbide tools were square, positive rake, throw-away inserts held in a standard 6° positive rake "Carboloy" holder with a 15° side cutting edge angle. Two grades were used; Carboloy grade 350, 3/4 in. square x 1/16 in. nose radius, and Carboloy grade 370, 1/2 in. square x 1/32 in. nose radius.

Primary emphasis was placed upon tool life and surface finish, with secondary emphasis upon chip formation. Tool failure criteria were established as total failure for HSS tools and 0.015 in. flank wear for carbide tools. Surface roughness was measured with a Micrometrical Manufacturing Company "Profilometer" at the beginning and end of a test run, and at various intervals in between. Chips were collected whenever chip form changes occurred.

Because of a limited supply of material, the majority of the tests were confined to HSS applications with a tool shape of 8, 14, 6, 6, 6, 15, 3/64, at a depth of cut of 0.070 in. (constant for all tests) and a feed of 0.0065 ipr. However, shorter test series, including some sharp tool tests, were conducted to find the effects of tool shape and feed upon the test criteria. Carbide cutting speeds on the C1144 steels were much higher than anticipated, and required speeds could not be reached on the machine with the given bar diameters and keep tool lives within bounds of the quantity of material available. Therefore, it was necessary to stop a number of tests short of the preferred flank wear at failure.

TEST RESULTS

CHIP FORMATION

Chip formation characteristics were noted with respect to four variables: tool shape, cutting velocity, feed, and cutting time. In each case, the C1144 materials demonstrated a greater inherent ability to produce small, broken chips than did the C1141. The C1144 is rated slightly higher than the modified grade, particularly at light feeds and low velocities. At heavy feeds, or high velocities, the two gave very similar results. Typical behavior is illustrated in Figs. 1 and 2 for tool shape 8, 14, 6, 6, 6, 15, 3/64, which was the basic shape for tool life tests.

Sharp tool tests, similar to those represented in Fig. 1, were repeated with tool shapes 8, 14, 6, 6, 6, 15, 1/8 and 8, 8, 6, 6, 6, 0, 0.020. The larger nose-radius tool gave larger chips and accented even more the differences between the two grades of steels. The more severe shape of the 0.020 nose-radius tool reduced the differences. At higher velocities, regardless of tool shape, all three materials produced similar, undesirable chips when sharp tools were used, as may be noted for zero time in Fig. 2. However, with continuous cutting short chips were produced from each material after the initial stages of tool wear. The C1144 steels hold the advantage in that shorter time intervals are required. Cold drawing did not materially affect chip formation characteristics.

TOOL LIFE

Tool-life results gave the most distinguishable differences among the three work materials, and yet were more affected by cutting conditions, leading to a positive and complete reversal of behavior of the two C1144 steels with HSS and carbide cutting tools. The results of all tests are tabulated in Tables II, III, IV, and V. Many of these results have been plotted in Figs. 3 and 4.

TABLE II

EFFECT OF TOOL SHAPE ON TOOL LIFE—HR STEEL

Operation: Turning
Tool Material: T-1, HSS
Tool Shape: As indicated

Velocity: 250 fpm
Depth of Cut: 0.070 in.
Feed: 0.0065 ipr

Tool Shape	Tool Life, min		
	C1144	C1144 Modified	C1141
8, 14, 6, 6, 6, 15, 3/64	27.57	12.62	6.32
8, 8, 6, 6, 6, 15, 0.020	20.26	7.45	1.70
8, 8, 6, 6, 6, 0, 0.020	5.49	1.32	0.65

TABLE III

HOT-ROLLED STEELS—TOOL LIFE AND SURFACE ROUGHNESS DATA

Operation: Turning	Tool Material: T-1, HSS
Fluid: Dry	Tool Shape: 8, 14, 6, 6, 6, 15, 3/64
Depth of Cut: 0.070 in.	

Velocity, fpm	Tool Life, min			Axial Surface Roughness, μin. rms		
	C1144	C1144 Modified	C1141	C1144	C1144 Modified	C1141
Feed: 0.0065 ipr						
357	0.13					
305	2.53			60-90*		
302		1.45			60-85	
300	3.47			60-130		
294	6.13	0.79	0.97	80-150	110-145	80-95
	5.42	0.99		70-140	120-140	
	8.10			90-135		
285		2.70	1.45		80-110	70-80
281	11.43	4.00	1.42	75-190		70-85
	11.07	4.39			70-95	
276	8.91			70-130		
270		5.05			90-120	
265	14.80	6.34	2.60	90-110	75-125	100-150
260	20.28					
258	22.57	7.26	0.81		See Fig. 8	
		11.70				
251	27.57	12.62	6.32	75-230	100-125	90-115
244		14.61			80-110	
240	N.F.**	19.70	6.21		See Fig. 7	
230	50.67	16.15	12.05	95-110	90-130	90-130
215		31.90	30.76		100-140	90-120
205		97.25	79.75		95-140	80-375
200	N.F.**	N.F.**	N.F.**		See Fig. 7	
150	N.F.**	N.F.**	N.F.**		See Fig. 7	
Feed: 0.0208 ipr						
170	0.35			450 (75)***		
130	4.10	3.42	1.69	350-400 (40-90)	300-500 60-90)	240-300 (80-80)
113	9.92	12.70	8.15	200-300 (70-110)	400-500 (55-70)	150-300 (80-150)

*Initial roughness—roughness just before failure. Peripheral roughness not recorded on most tests.

**No failure. Surface finish test. Stopped at 25 min.

***Peripheral roughness in parentheses.

TABLE IV

COLD-DRAWN STEELS—SUMMARY OF HSS TOOL LIFE AND SURFACE ROUGHNESS DATA

Operation: Turning, dry
Depth of Cut: 0.070 in.
Feed: 0.0065 ipr

Tool Material: T-1, HSS
Tool Shape: 8, 14, 6, 6, 6, 15, 3/64

Velocity, fpm	Tool Life, min			Surface Roughness vs. Time, µin. rpm																	
				C1144						C1144 Modified						C1141					
	C1144	C1144 Modified	C1141	Begin	1 min	4 min	9 min	16 min	Failure	Begin	1 min	4 min	9 min	16 min	Failure	Begin	1 min	4 min	9 min	16 min	Failure
330	1.34			40 (25)*	50 (30)				60 (30)												
300	4.56			60 (25)	70 (25)	80 (35)			100 (40)												
289	2.73			55 (25)	65 (25)				70 (35)												
280	8.08			65 (25)	75 (25)	80 (40)			95 (30)												
275		5.10								80 (70)	85 (65)	100 (90)			110 (100)						
270	10.98	2.23	0.70	95 (50)	95 (35)	90 (45)	90 (50)		90 (55)	70 (35)	70 (40)				110 (35)						
261	10.79	8.56		100 (50)	100 (60)	110 (80)	110 (80)		110 (85)	70 (30)	70 (25)	100 (55)			120 (60)						
257	17.25	10.08		70 (50)	75 (45)	90 (60)	110 (70)	130 (90)	140 (95)	60 (30)	70 (25)	75 (25)	95 (30)		90 (40)						
251		12.50	1.67							65 (35)	80 (35)	90 (60)	100 (70)		110 (75)	100 (40)	110 (40)				120 (80)
245		23.22								50 (30)	55 (30)	70 (40)	80 (45)	110 (50)	120 (60)						
235			1.92													120 (95)	150 (80)				160 (90)
233			8.90													70 (35)	90 (50)	100 (60)			100 (45)
231			15.29													80 (40)	90 (45)	100 (60)	100 (65)		115 (55)
227			16.34													60 (30)	65 (35)	100 (45)	110 (55)	110 (65)	110 (65)

*Numbers in parentheses represent surface roughness around the periphery. Others represent axial roughness perpendicular to feed marks.

TABLE V

HOT-ROLLED STEELS—SUMMARY OF CARBIDE TOOL LIFE AND SURFACE ROUGHNESS DATA

Operation: Turning, dry
Depth of Cut: 0.070 in.

		Carboloy Grade 350 0, 6, 11, 5, 15, 15, 1/16																					Carboloy Grade 370 0, 6, 11, 5, 15, 15, 1/32						
		Feed: 0.0065 ipr															Feed: 0.0168 ipr						Feed: 0.0065 ipr						
		C1144		C1144 Modified				C1141									C1144	C1144 Modified		C1141			C1144			C1144 Modified			C1141
Velocity, fpm:		1495	912	1725	1460	1425	905	1700	1530	1310	1190	1140	995	900	840	775	900	900	1310	900	1300	1400	605	912	900	910	905	900	900
Total Cutting Time, min:		6.10	11.30	11.50	2.92	12.27	10.87	3.21	2.86	3.50	5.50	6.10	6.68	10.30	7.50	14.50	6.56	7.20	3.67	6.30	2.84	2.00	20.18	14.32	18.84	11.65	19.62	20.53	6.97
Flank Wear, in.:		.0165	.0069	.0167	.0037	.0039	.0034	.0577	.0205	.0152	.0152	.0153	.0146	.0156	.0151	.0156	.0093	.0042	.0185	.0151	.022	.016	.0046	.0154	.0158	.0038	.0052	.0041	.0153
Tool Life, min:		5.40	---	10.70	---	---	---	2.00	2.30	3.40	5.40	5.90	6.90	9.50	7.40	13.70	---	---	3.40	6.20	2.40	1.9	---	13.95	18.20	---	---	---	6.2
Surface Roughness vs. Time, µin. rms	Begin	55 (15)	85 (30)	140 (40)	70 (14)	105 (15)	100 (38)	85 (8)	70 (9)	90 (8)	50 (12)	140 (25)	75 (20)	70 (15)	65 (30)	60 (30)	220 (15)	170 (12)	180 (8)	200 (18)	100 (35)	200 (8)	60 (25)	40 (35)	-- --	50 (30)	-- --	-- --	40 (10)
	1 min	50 (12)	75 (40)	200 (30)	95 (8)	95 (15)	90 (58)	95 (18)	90 (20)	95 (10)	40 (15)	120 (25)	95 (25)	65 (32)	65 (30)	60 (30)	210 (20)	230 (16)	200 (10)	190 (12)	120 (55)	170 (15)	90 (20)	50 (45)	-- --	65 (25)	-- --	-- --	70 (15)
	4 min	60 (15)	100 (40)	105 (25)	-- --	100 (20)	75 (68)	-- --	-- --	-- --	65 (32)	95 (20)	80 (20)	75 (45)	80 (35)	70 (30)	190 (15)	220 (30)	-- --	200 (15)	-- --	-- --	120 (25)	65 (40)	-- --	95 (35)	-- --	-- --	95 (28)
	9 min	-- --	100 (20)	130 (50)	-- --	90 (35)	110 (35)	-- --	-- --	-- --	-- --	-- --	-- --	95 (35)	-- --	95 (30)	-- --	-- --	-- --	-- --	-- --	-- --	155 (28)	75 (30)	-- --	140 (35)	-- --	-- --	-- --
	16 min	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	145 (30)	-- --	-- --	-- --	-- --	-- --	-- --
	Failure	85 (38)	-- --	-- --	110 (28)	-- --	95 (42)	-- --	50 (30)	100 (14)	80 (38)	80 (25)	110 (20)	110 (35)	110 (40)	100 (30)	-- --	-- --	210 (28)	150 (40)	120 (50)	200 (30)	-- --	140 (45)	-- --	-- --	-- --	-- --	110 (35)

The majority of HSS tests were made with a standard tool shape of 8, 14, 6, 6, 6, 15, 3/64 at a constant depth of 0.070 in. and a feed of 0.0065 ipr on both the hot-rolled and cold-drawn materials. A few tests at a feed of 0.0208 ipr were conducted on the hot-rolled materials only.

The results of tests on the hot-rolled steels, as plotted in Fig. 3a, show that there is a definite separation of the three materials at a feed of 0.0065 ipr, with the C1144 showing a 15% and 8% higher velocity at a 30-min tool life than the C1141 or C1144 modified, respectively. These same relative positions were held with two other tool shapes as indicated in Table II. At a feed of 0.0208 ipr, however, the two C1144 steels gave almost identical results within the limited number of tests run. It may be noted, also, that the tool-life curve for the C1144 material is the only one showing a tendency for a double slope, with greater sensitivity at higher velocities.

Tests on the cold-drawn materials were to be in the nature of spot checks only, and tool lives had to be short because very little material was available. However, the results, as plotted in Fig. 3b, are rather interesting, for cold drawing has affected the slopes of the tool life curves of the two C1144 steels, causing them to converge at a tool life of about 30 min, thus erasing the differences that existed on the hot-rolled materials.

Carbide tests were also to be in the nature of spot checks, and the results achieved were somewhat unexpected. However, the results were consistent with two carbide grades, two feeds, and over a range of cutting velocities. Repeat tests with HSS and carbide tools on the same bars of steel verified earlier results. Bar samples were even sent to the Bethlehem Steel Company for confirmation of identification.

Typical of the behavior are the partial results plotted in Fig. 4 for a Carboloy grade 350 at a feed of 0.0065 ipr, we note that the tool life (0.015 in. flank wear) is twice as long on the modified C1144 as it is on the standard (10.7 min to 5.4 min), even though the velocity is 15% higher (1725 fpm to 1495 fpm). Comparing the two materials on the basis of the partial wear results for the same carbide (Table V), at a velocity of 900 fpm and feeds of either 0.0065 ipr or 0.0168 ipr, the standard material gave more than twice the flank wear in approximately the same time interval. Similar results were achieved with the 370 grade carbide. With this grade, wear and cutting time on the two steels correlated very well when the cutting velocity on the standard steel was reduced from 900 to 600 fpm. In other words, the modified steel could run at a 50% higher speed for the same tool wear in a given time. In all instances, the C1141 is rated well below the other two steels.

We did not make special attempts during this investigation to seek the causes of the unexpected behavior. Tools were examined, however. Even though the amount of wear was greater, the C1144 tools usually had more uniform flank wear with less notching at the peripheral point of contact. Crater wear was quite similar, although there was evidence that the C1144 had more unstable "smear" characteristics. Light smear was found in the crater as well as on the "lip" around the cutting edge. On the C1144 modified tools, the smear, perhaps even smaller, was confined to the lip. The fax-film reproductions shown in Fig. 15 also illustrate the greater smear tendencies of the standard C1144. If the smear with the modified steel is more stable, this could have some influence in reducing wear. Smear was found in the craters of both tools when flank wear was carried to 0.015 in. In any event, the amount of smear was small.

SURFACE FINISH

Surface-roughness measurements with a Profilometer consist of two main groups: (1) sharp tool results versus feed and tool shape with HSS tools on hot-rolled materials, and (2) roughness versus cutting time at various velocities with HSS tools on hot-rolled and cold-drawn steels, and carbide tools on hot-rolled materials. In the beginning, these measurements were made in the usual manner by traversing the feed marks, parallel to the axis of the workpiece. However, the values did not always separate the surfaces in accord with visual interpretations. Therefore, readings were added in a second direction parallel to the feed marks around the periphery of the workpiece. The peripheral values seemed to better reflect the smearing and tearing tendencies of the material, and in many instances, surfaces which had lower axial values had much higher peripheral values.

Figures 5 and 6 show the axial and peripheral surface-roughness results of sharp tool tests. These results carry more meaning when they are compared with the fax-film reproductions of the surfaces shown in Fig. 7. Built-up edge and tear marks are evident in all materials in varying degrees of texture as influenced by cutting conditions. At low velocities, cutting tools with larger nose radii were effective at lower feeds, but produced badly torn surfaces at higher feeds. Critical combinations of cutting conditions may be noted for each of the work materials.

The inconsistencies in the relative values of surface roughness across the feed marks may be accounted for by the fact that feed marks in the form of ridges were usually much more prominent on the C1144 materials, particularly at higher feed rates. In contrast, it may be noted that the feed marks are much less pronounced on the C1141, but there is more tearing in between. Thus, it is probable that the ridges raised the axial roughness level of the C1144 steels even though the surface as a whole was of finer texture.

Although the sharp tool results show, at least to some extent, the inherent characteristics of each material, they do not predict the influence of time and tool wear. Figure 8 shows typical HSS results of the variations in surface quality experienced during continuous tests at given velocities on the hot-rolled steels, with a tool shape of 8, 14, 6, 6, 6, 15, 3/64 and a feed of 0.0065 ipr. On the basis of these results, the modified C1144 steel would have to be rated about equal to the C1144 at lower speeds, but definitely better at what appears to be a critical speed range for the C1144, from 200 to 260 fpm. The C1141 is rated consistently below the other two steels. Differences in surface texture may be noted in Figs. 9 and 10 for velocities of 150 and 258 fpm.

Tests performed in the cold-drawn steels show the surfaces to be more consistent and more stable at slightly lower roughness levels, as indicated in Figs. 11 and 12. Figure 11 shows a direct comparison between the hot-rolled and cold-drawn materials at identical cutting conditions. Both the axial and peripheral surface-roughness values are lowest on the modified C1144 steel. The surface reproductions in Fig. 12 can be compared directly with those in Fig. 10. Less tearing and streaking is noted on the cold-drawn steels.

So far, roughness has been compared on the basis of identical cutting conditions, which resulted in different tool-life values between the two C1144 materials. Figure 13 shows surface-roughness values for hot-rolled and cold-drawn steels plotted on the basis of cutting velocities which gave comparable tool life. The modified C1144 shows to advantage at the longer tool lives, with both axial and peripheral roughness of lower magnitude for both steel conditions. At the short tool lives, the relative standings of the two steels are reversed for the cold-drawn condition, particularly with respect to the roughness around the periphery. The results in Table IV show that velocity had a much greater effect on the cold-drawn C1144 than it did on the hot-rolled grade.

Typical results of the carbide tests are shown in Figs. 14, 15, and 16. Based on visual appearance, the C1141 material must be rated higher than the other two, and this observation is substantiated, at least in part, by the results shown in Figs. 14 and 16. The surfaces were cleaner, more highly polished, and less subject to streaking than either of the C1144 steels. The C1144 material had more evidence of smearing on the surface and had a tendency to streak more than the modified grade. Lower axial roughness values were recorded with the Profilometer, however, and one reason for this may be seen in Fig. 15. The feed marks on the modified steel are much more prominent. Apparently, the smearing tendency of the C1144 helped fill in the grooves, presenting a smoother path for the Profilometer. The smearing, however, is reflected in somewhat higher average levels of peripheral roughness.

The surfaces for the C1144 at 600 fpm, and the modified C1144 at 900 fpm (Fig. 15) can be compared on the basis of comparable tool wear in a comparable period of time. Both tools had less than 0.005 in. flank wear after 20 min of cutting. Streaking was not evident at the 600 fpm velocity on the C1144, but the surface was not so good as that of the modified steel.

CONCLUSIONS

The conclusions are based upon the results within the range of cutting variables used in this investigation. It is believed that sufficient numbers of tests were made to place a high reliability on chip formation and tool-life behavior for the given conditions. However, measured differences in surface quality were often small in magnitude, and in many instances, particularly with the C1144 steels, they were probably smaller than the variation one would expect in repeat runs on the same material. Under these circumstances, a statistical approach, involving many more tests, would be required for proper evaluation. There were, however, certain trends which were evident.

CHIP FORMATION

Of the three work materials, the C1144 had the greatest inherent ability to produce more desirable chips. They broke up more readily and in less time at given cutting conditions. The C1144 modified steel had similar tendencies and is rated just below the C1144, significantly above the C1141. Cold drawing had no effect on the relative behavior, and only a negligible effect in chip form.

TOOL LIFE

The C1141 is rated lowest of the three steels at all test conditions. However, the relative positions of the C1144 and the C1144 modified steels are influenced very strongly by cutting conditions. With HSS cutting tools, the modified C1144 is rated about 8-10% lower than the standard C1144 at a feed of 0.0065 ipr, but is rated equal to the C1144 at a feed of 0.020 ipr. With carbide tools, at either light or heavy feeds, the materials reverse position and the C1144 modified steel is capable of production rates as much as 50% higher than the standard C1144. Cold drawing does not affect the level of performance of the two C1144 steels appreciably, but it does modify the slopes of the tool-life curves so the two steels have comparable behavior at tool lives of 30 min or more.

SURFACE FINISH

The C1141 steel is rated below the other steels with HSS tools, but is rated at least equal to the C1144 materials with carbide tools. Based upon the combined results of axial and peripheral roughness and visual inspection, the modified C1144 is rated no less than the standard C1144 with either HSS or carbide tools at practical speed ranges. Cold drawing reduces the smear and tearing tendencies of all steels, and results in a more uniform and stable surface finish. It is particularly effective in reducing the surface roughness of the C1144 steel at high cutting velocities.

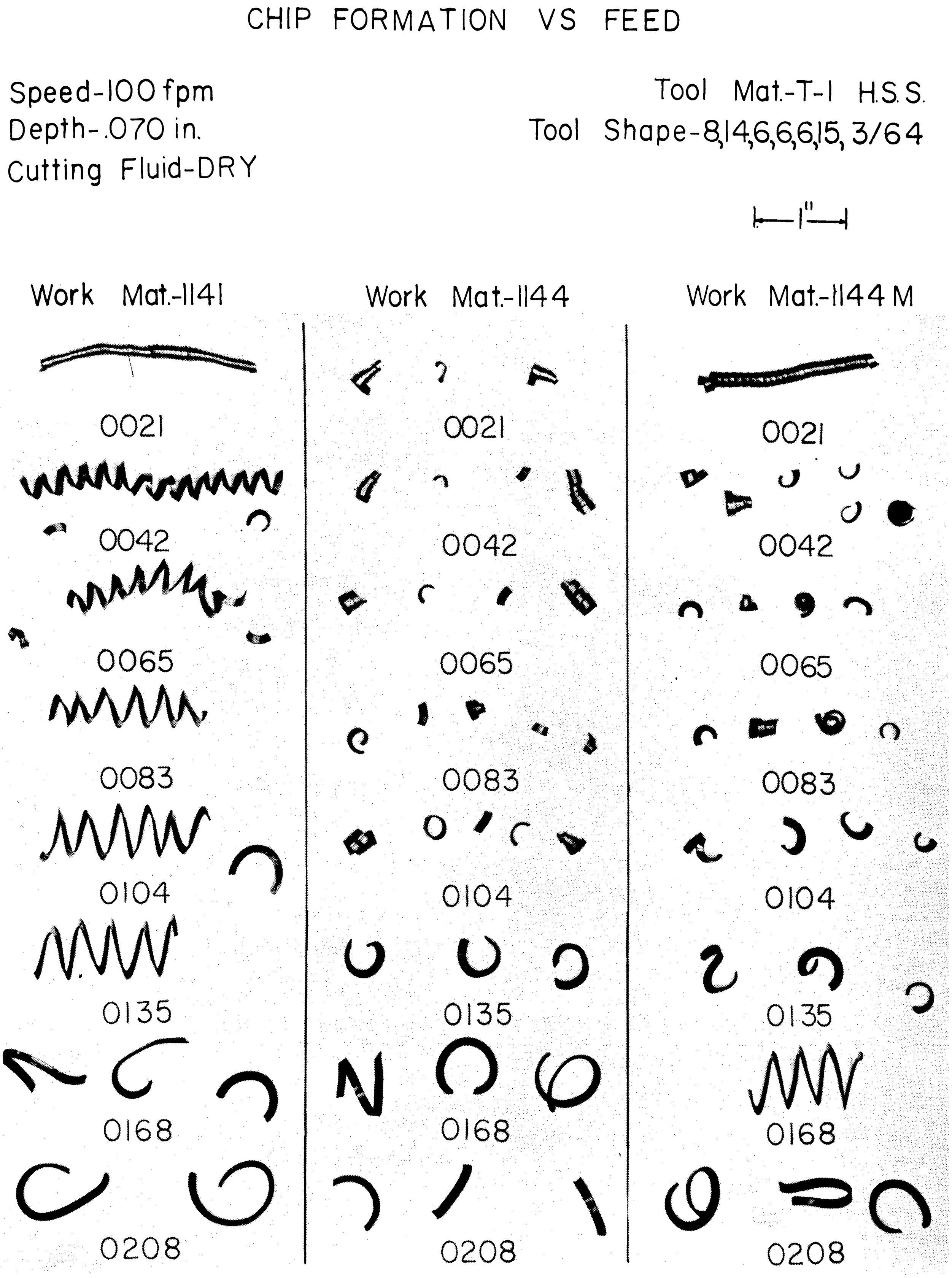


Fig. 1. Chip formation vs. feed. Sharp tool results. Similar tests with tool shapes 8, 14, 6, 6, 6, 15, 1/8 and 8, 8, 6, 6, 6, 0, 0.020 gave larger and smaller chips respectively, but relative results were the same. At 200 fpm, differences among materials were far less pronounced.

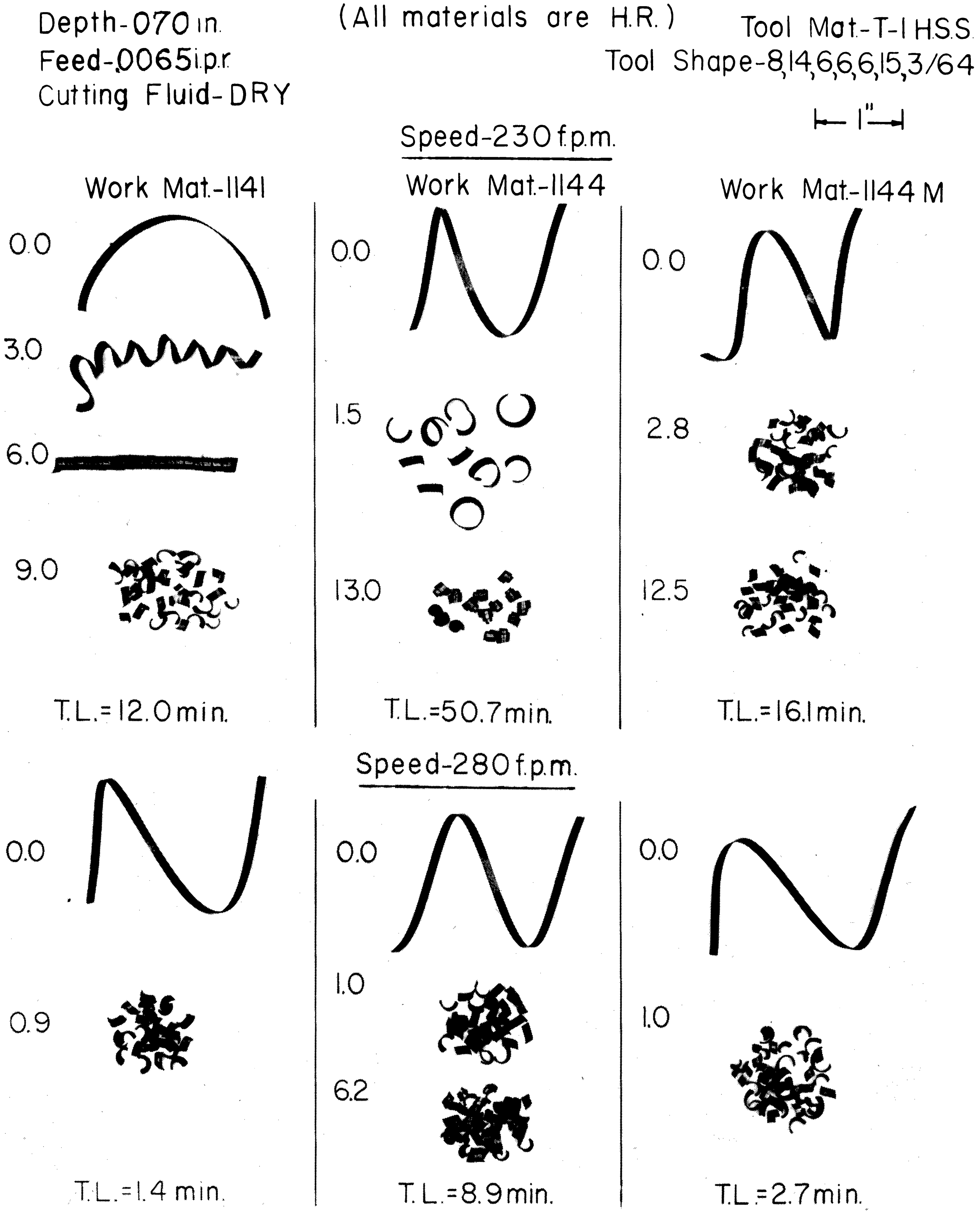


Fig. 2. Chip formation vs. cutting time. Numbers alongside chips represent time in minutes at which form changes were observed. Note that the C1141 chips at 230 fpm changed form, but were long and continuous for 9 min. The others changed abruptly from large, long, helical spirals to broken form at times indicated.

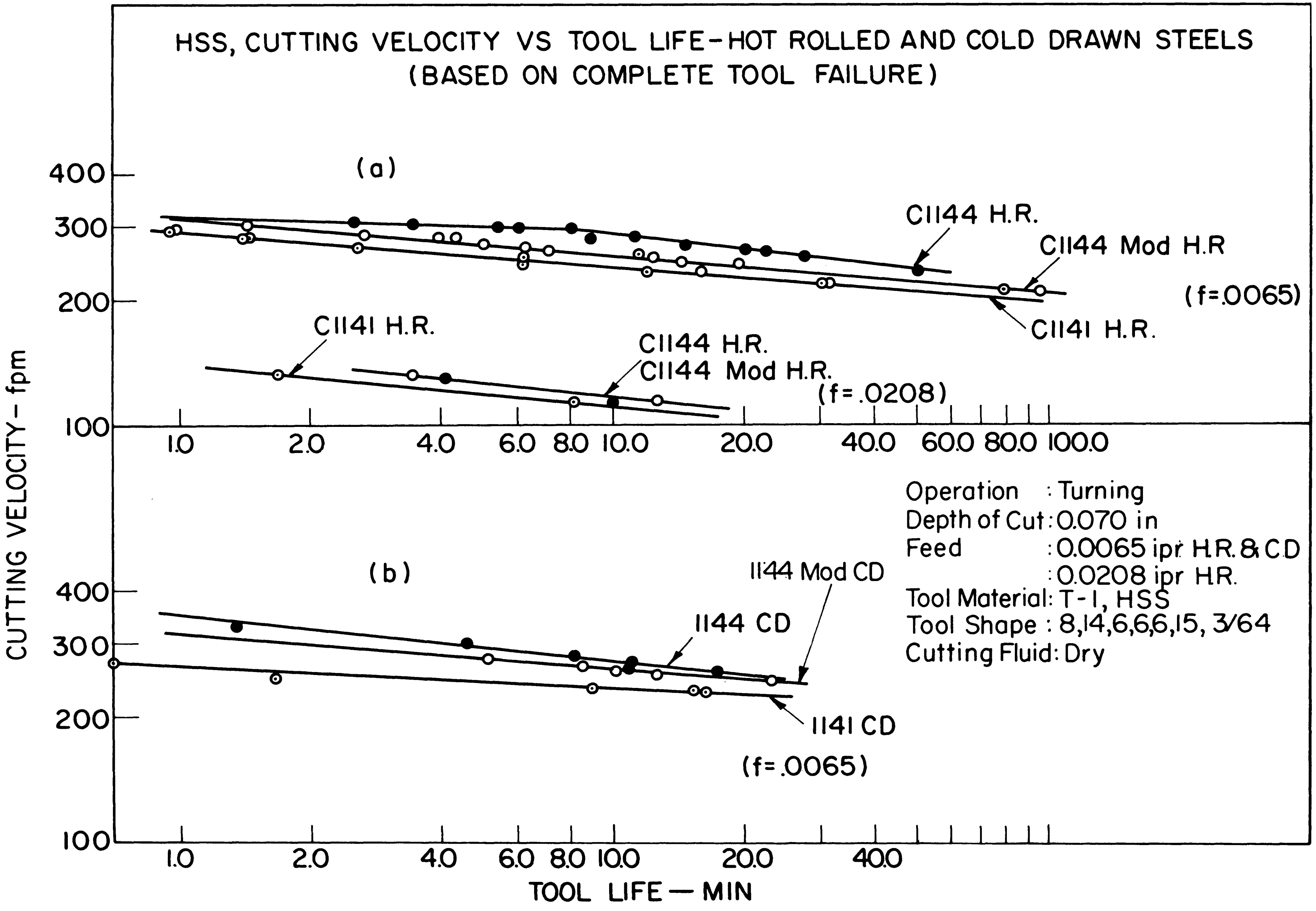


Fig. 3. Tool life curves for hot-rolled and cold-drawn steels as plotted from HSS results in Tables III and IV, respectively.

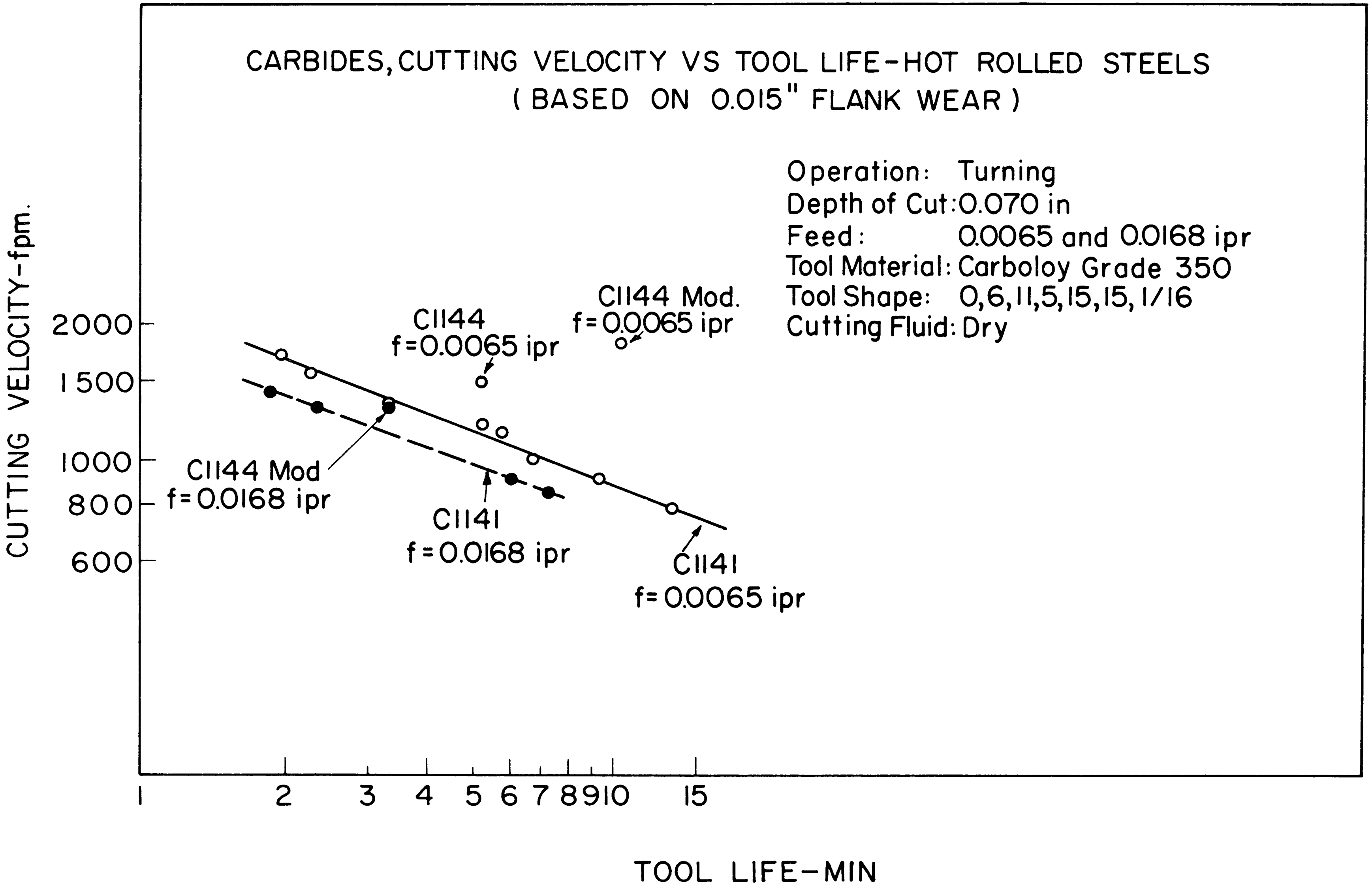


Fig. 4. Carbide tool life curves on hot-rolled materials as plotted from results in Table V. Only those points which resulted in 0.015 in. flank wear have been plotted.

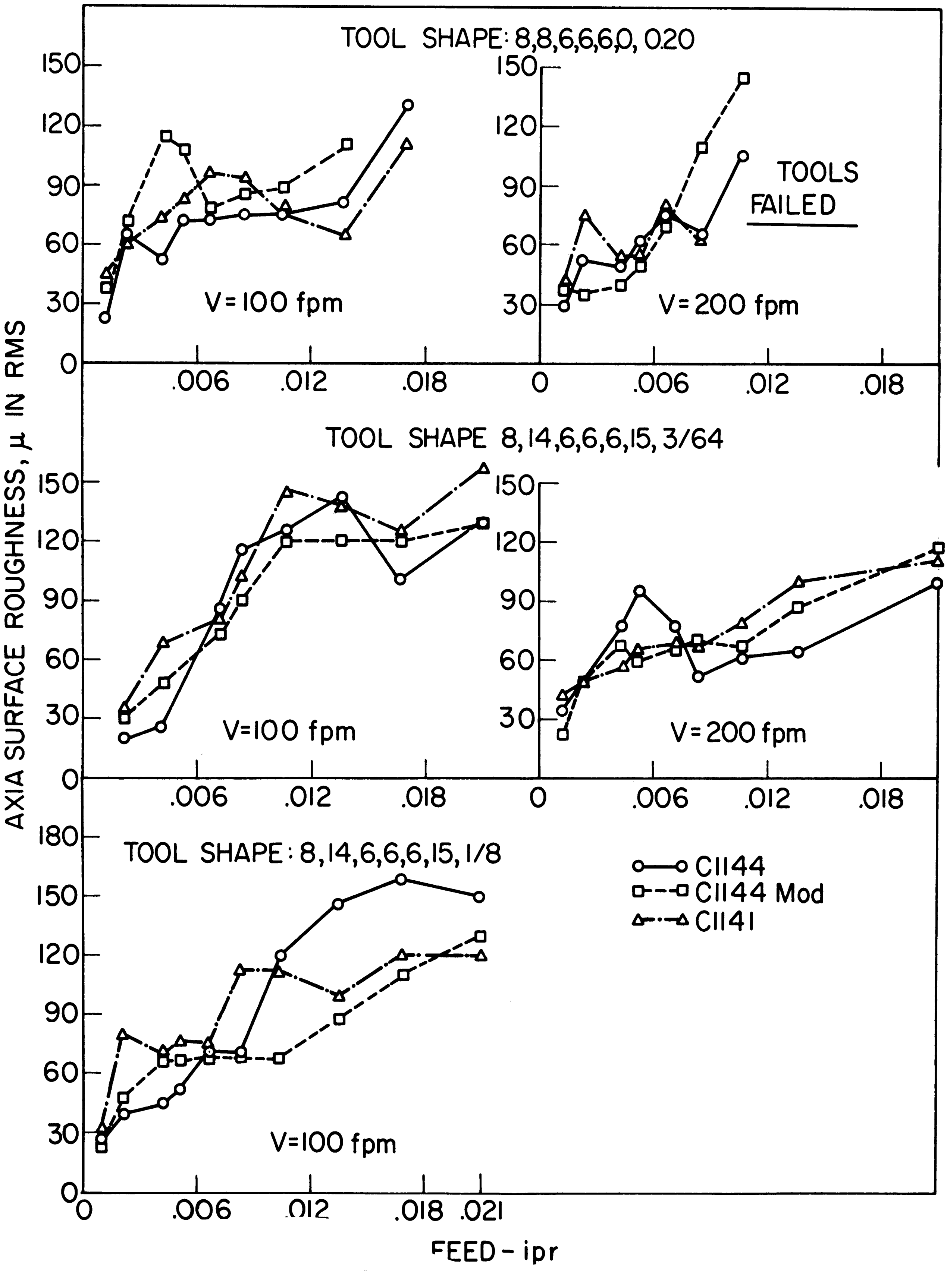


Fig. 5. Axial surface roughness vs. feed and tool shapes at 100 and 200 fpm on H.R. steels. Sharp HSS tool results, cut dry. Depth of cut, 0.070 in. Companion peripheral roughness plotted in Fig. 6. Fax film impressions of surfaces at several feeds reproduced in Fig. 7.

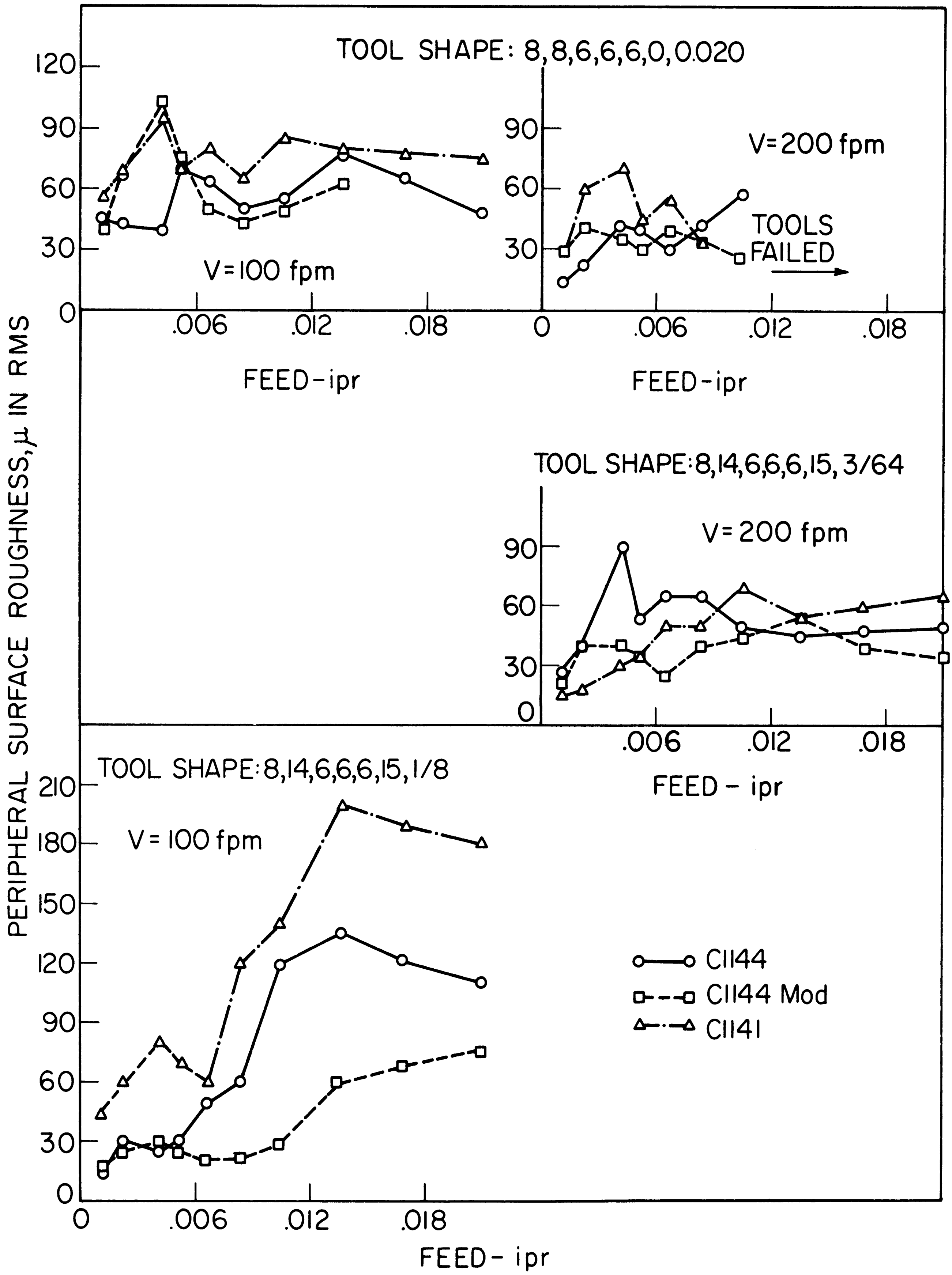
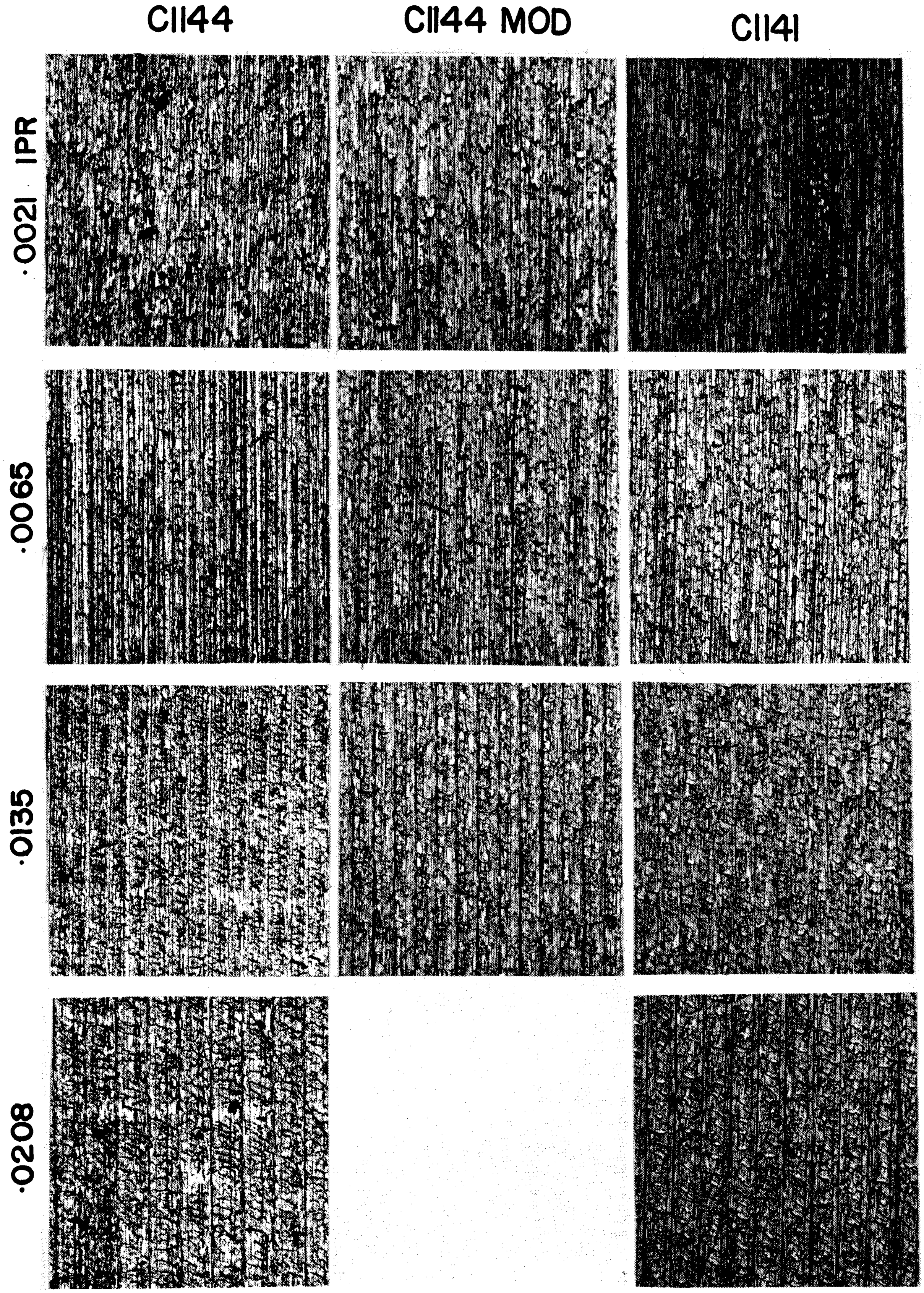
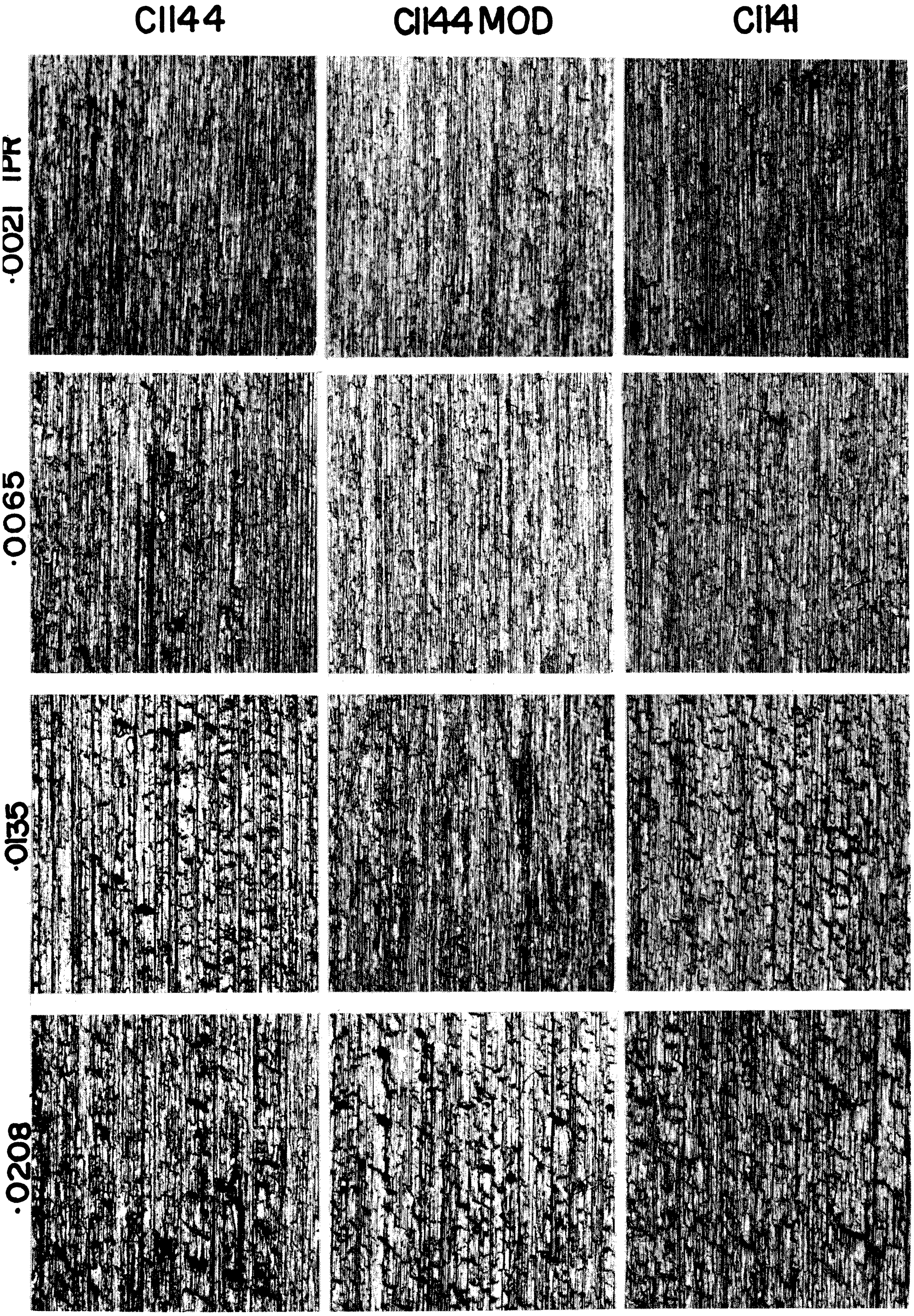


Fig. 6. Peripheral roughness of same surfaces represented in Fig. 5.



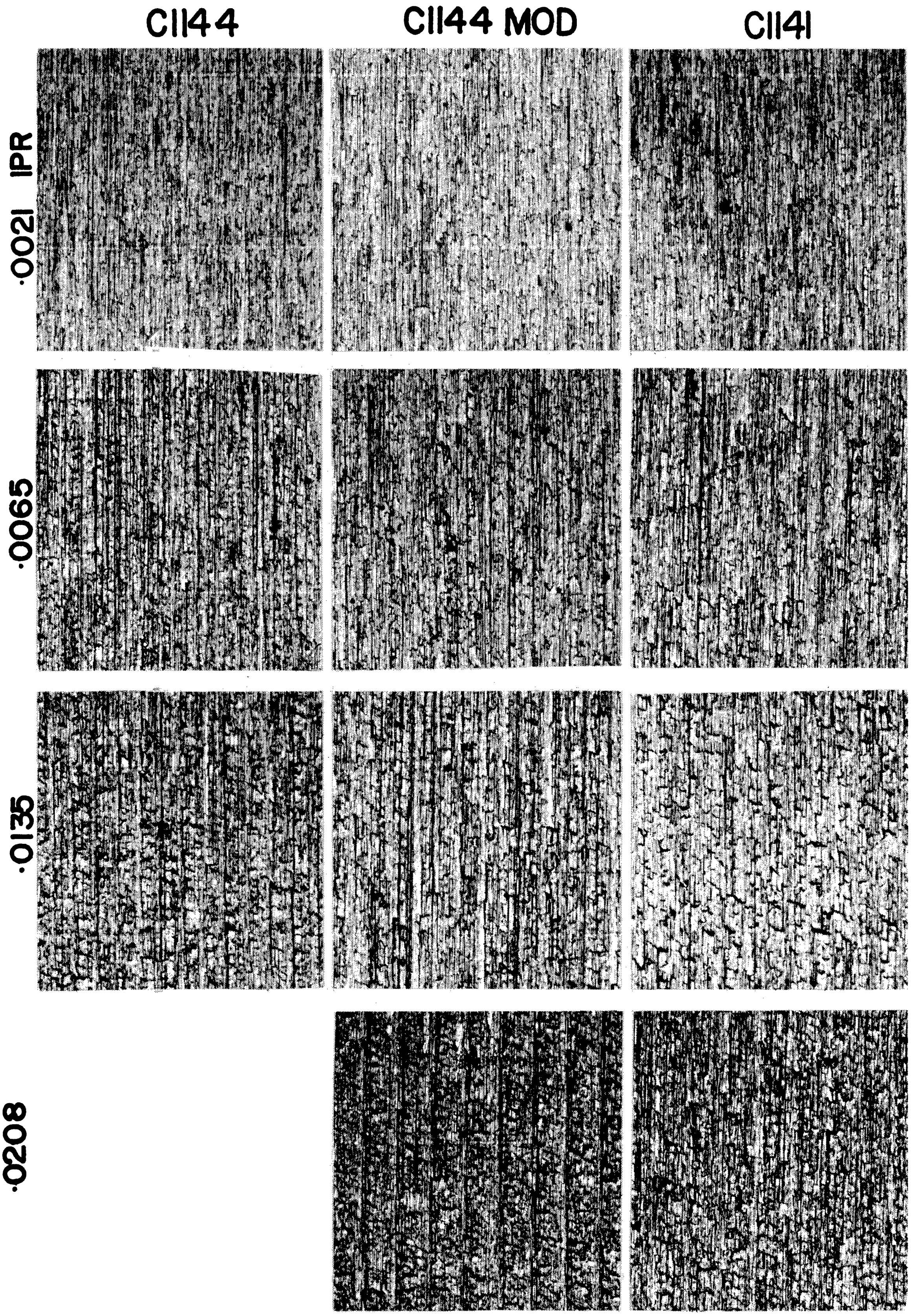
(a) V = 100 fpm; tool shape 8, 8, 6, 6, 6, 0, 0.020.

Fig. 7. Fax film reproductions of some of the surfaces whose roughness values are shown in Figs. 5 and 6.



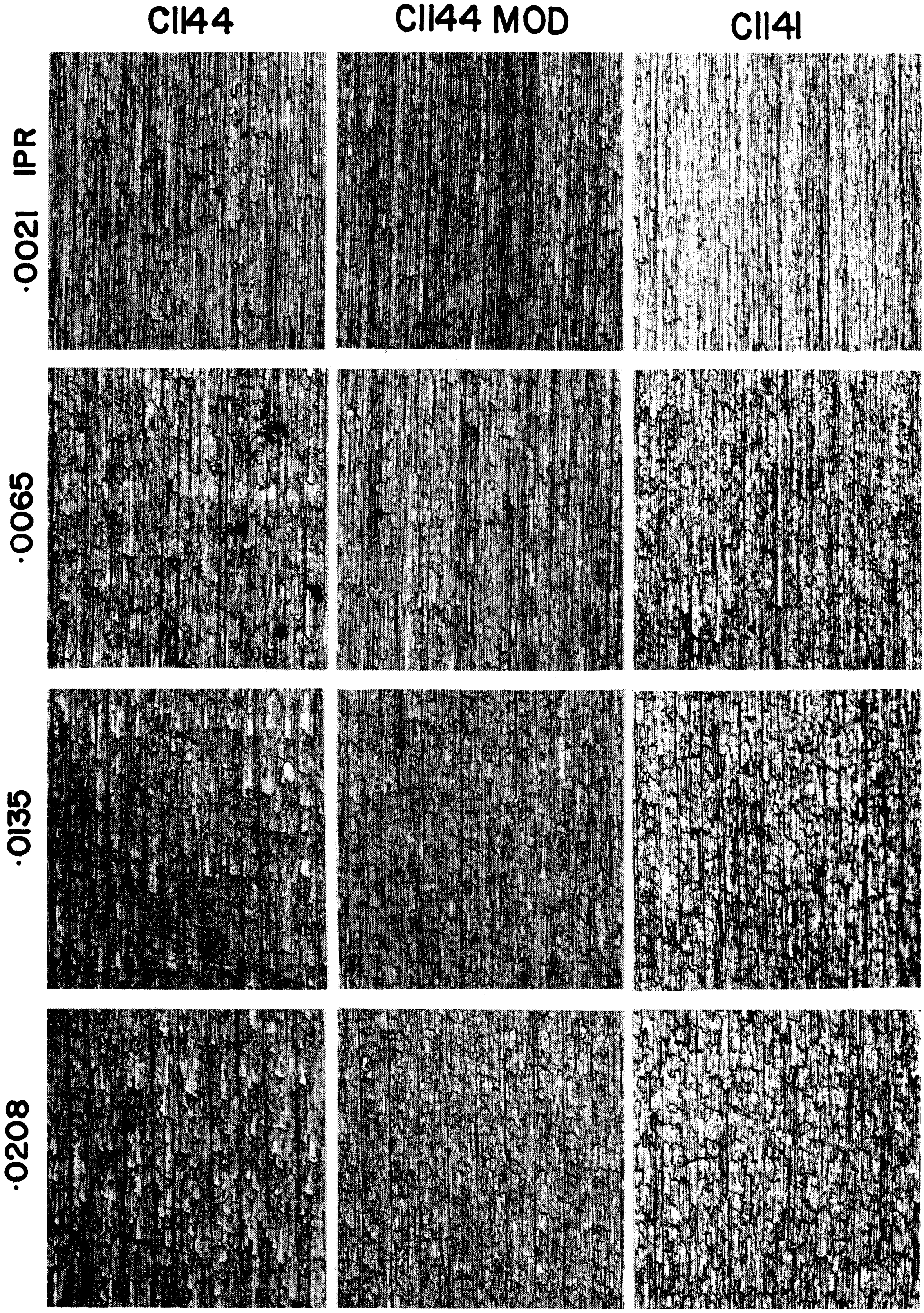
(b) V = 100 fpm; tool shape 8, 14, 6, 6, 6, 15, 1/8.

Fig. 7. (Continued)



(c) V = 100 fpm; tool shape 8, 14, 6, 6, 6, 15, 1/16.

Fig. 7. (Continued)



(d) V = 200 fpm; tool shape 8, 14, 6, 6, 6, 15, 1/16.

Fig. 7. (Concluded)

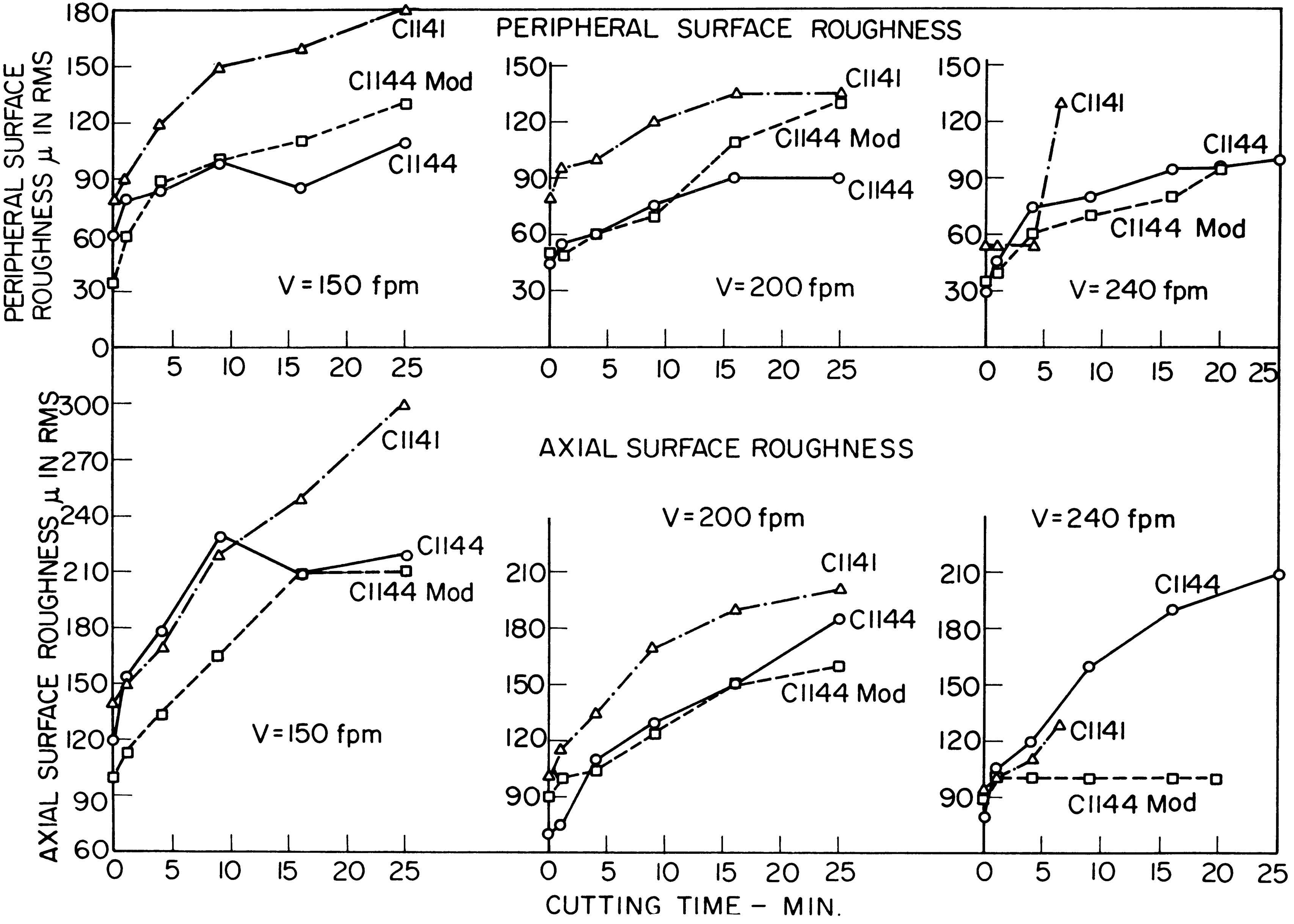


Fig. 8. Surface roughness vs. time on hot-rolled steels with HSS tools at various velocities. Tool shape 8, 14, 6, 6, 6, 15, 3/64; f = 0.0065 ipr; d = 0.070 in. cut dry.

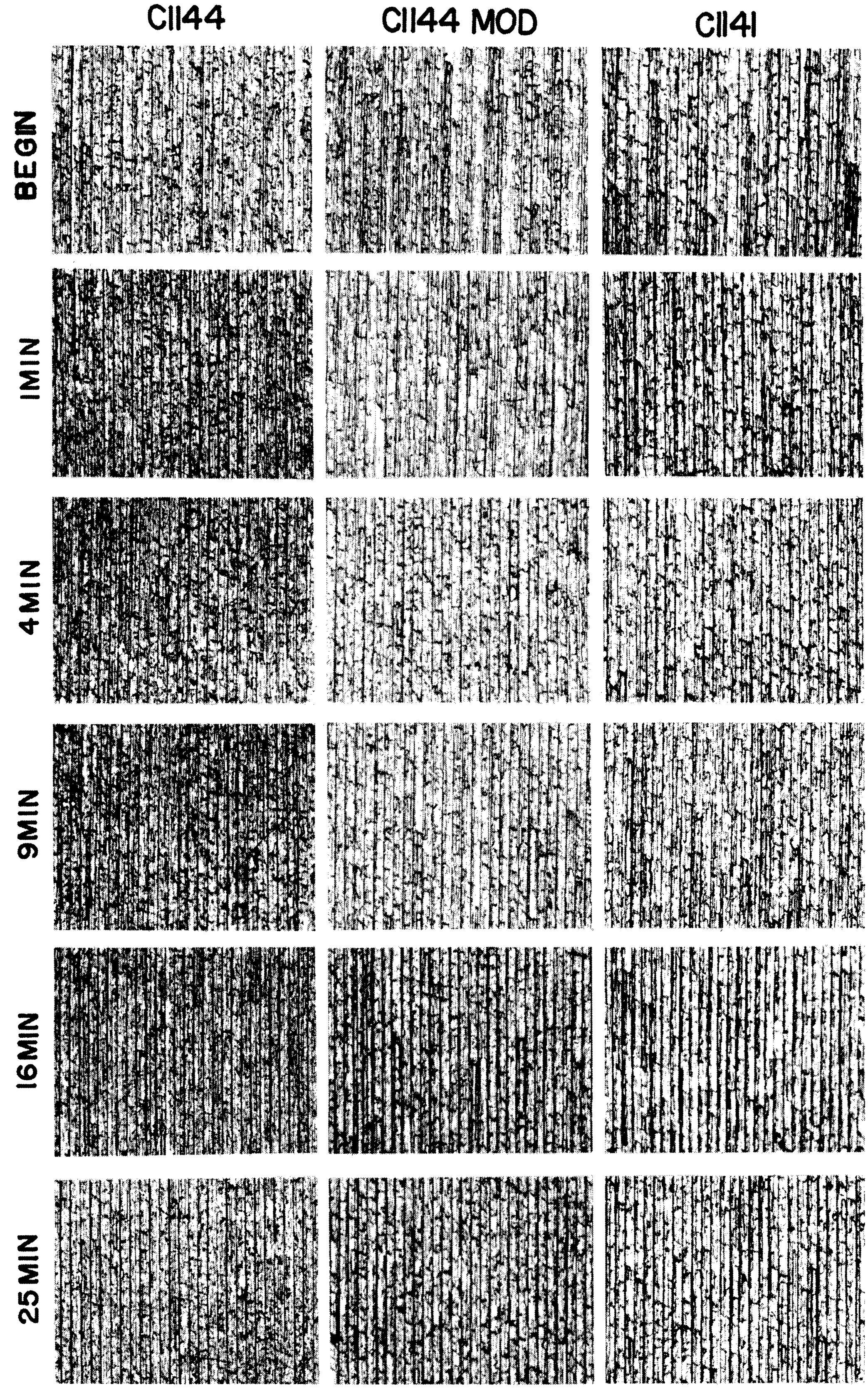


Fig. 9. Fax film reproductions of surfaces produced at a velocity of 150 fpm with cutting conditions listed in Fig. 8.

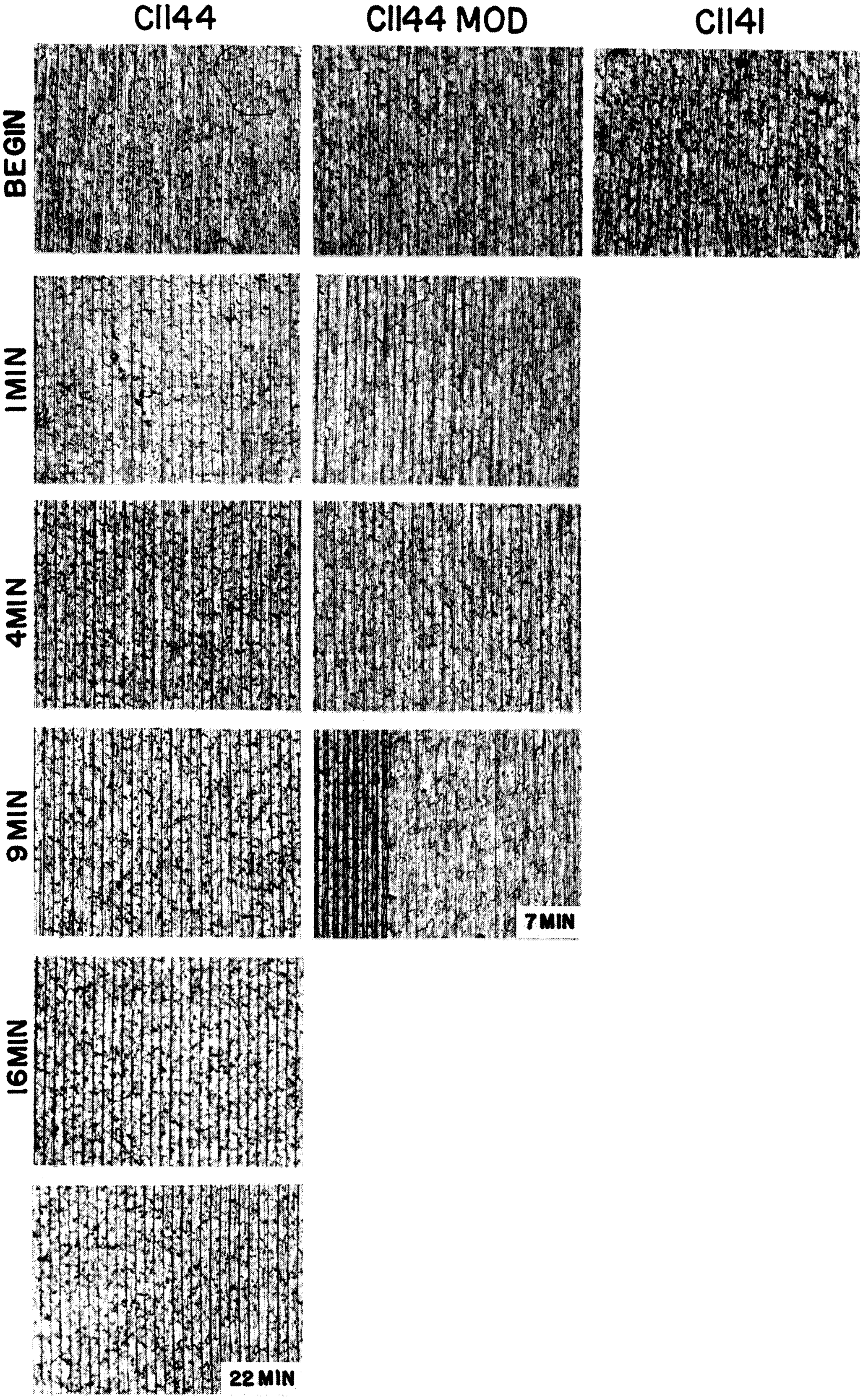


Fig. 10. Fax film reproductions of surfaces produced at 258 fpm with cutting conditions listed in Fig. 8.

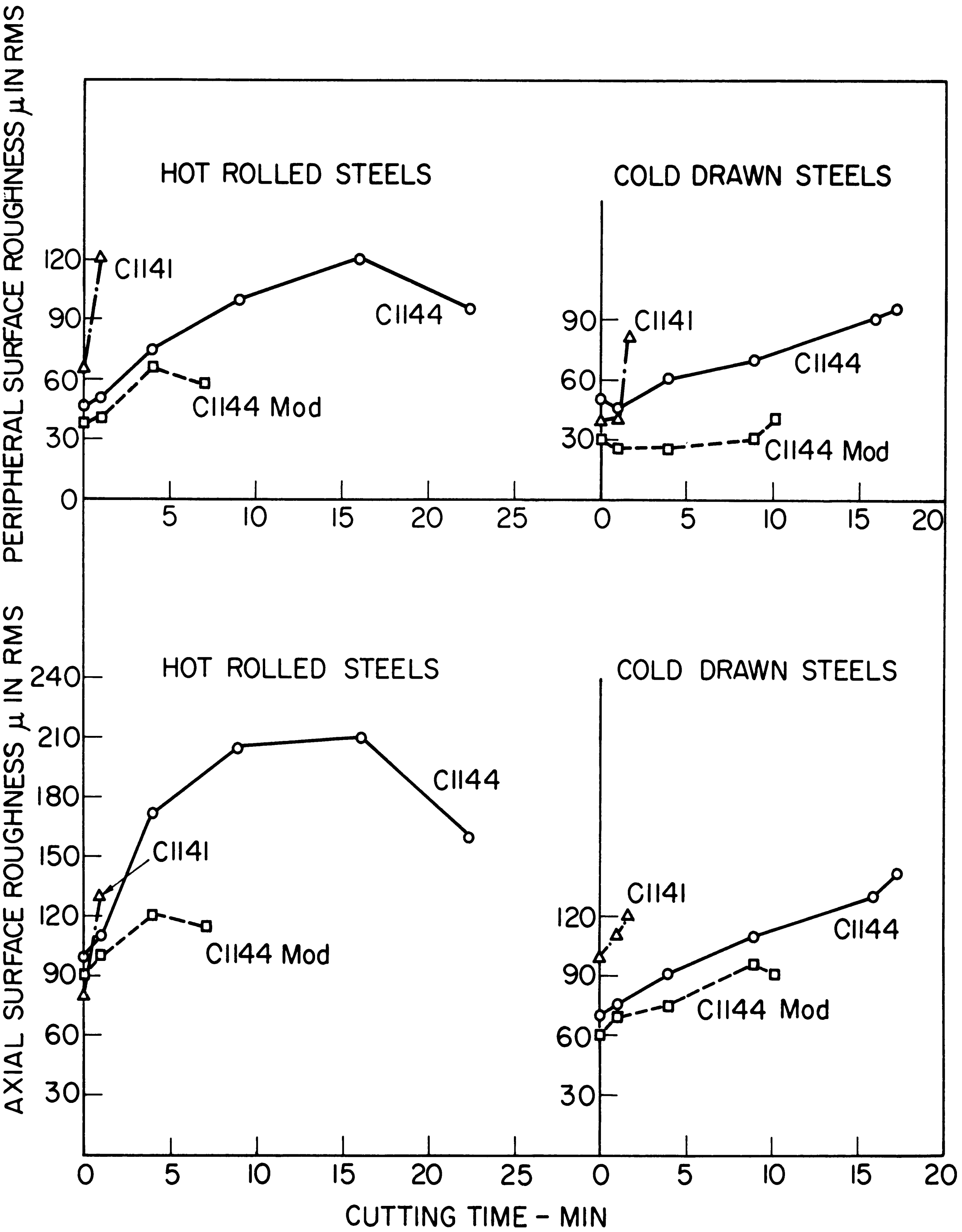


Fig. 11. Comparison of surface roughness of hot-rolled and cold-drawn steels at a velocity of 258 fpm under cutting conditions listed in Fig. 8.

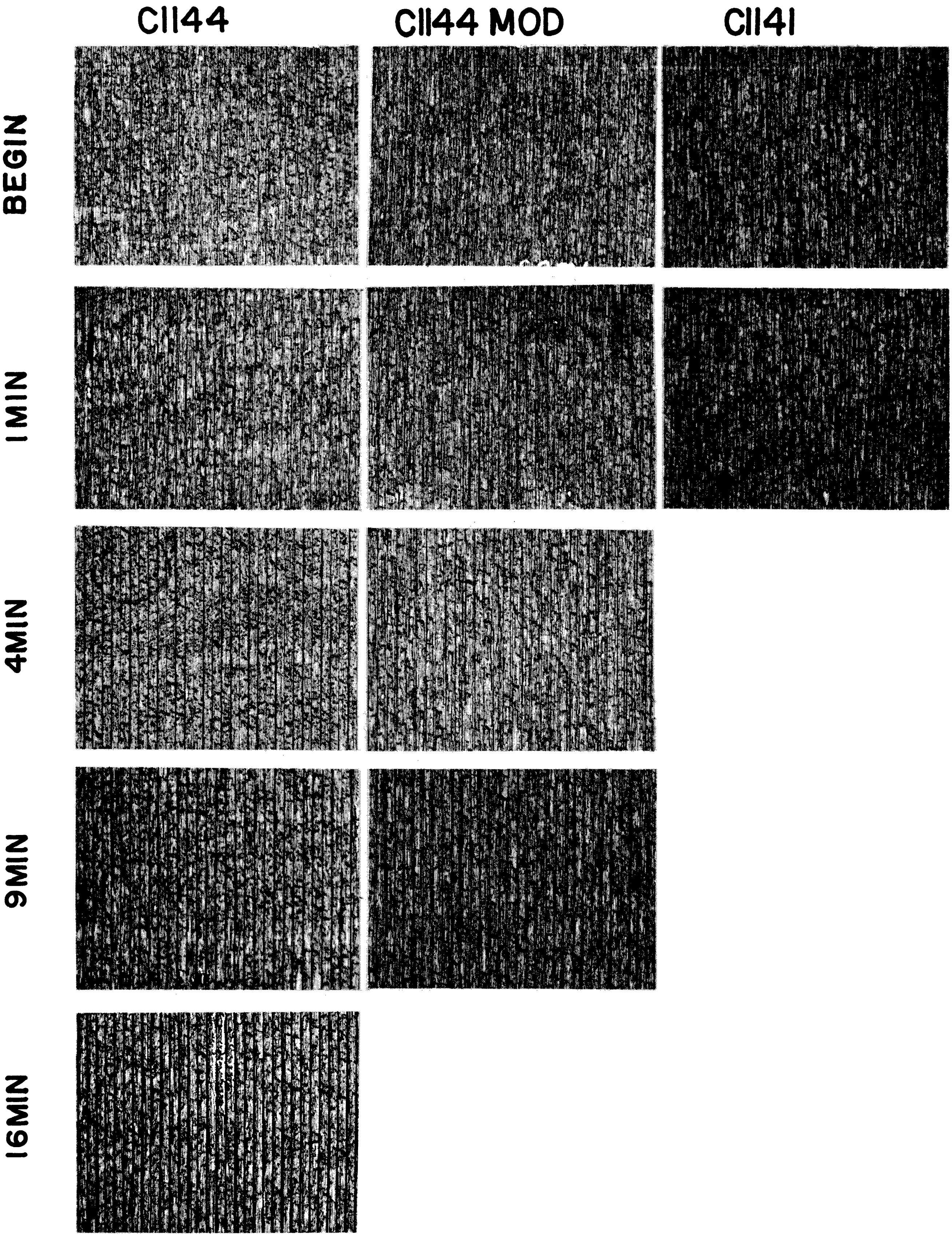


Fig. 12. Fax film reproductions of surfaces produced on cold-drawn steels at 258 fpm under cutting conditions listed in Fig. 8. May be compared with hot-rolled steel results in Fig. 10.

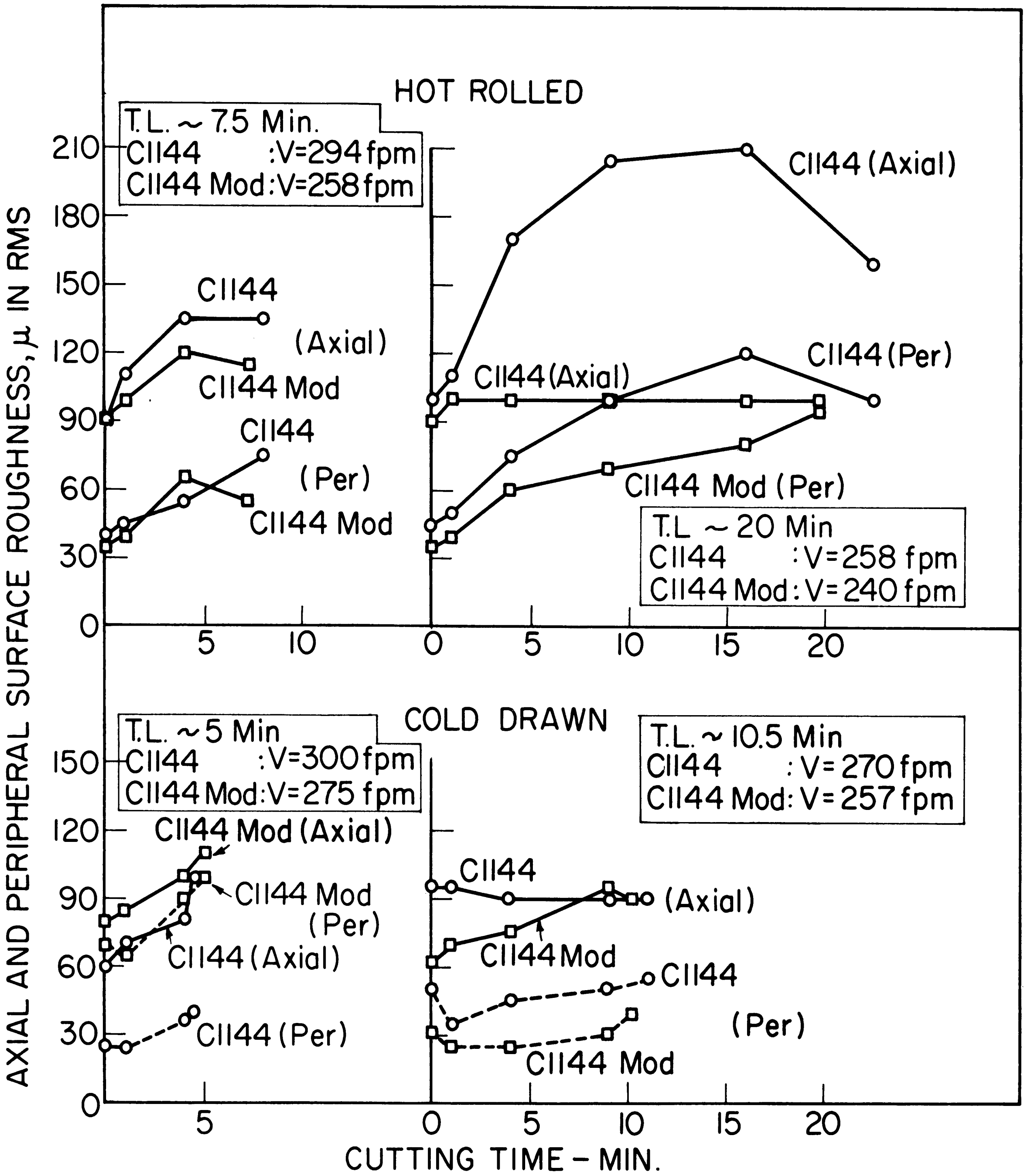


Fig. 13. Surface roughness vs. time on hot-rolled and cold-drawn steels based on velocities which gave comparable tool life. Size of cut and tool shape as listed in Fig. 8.

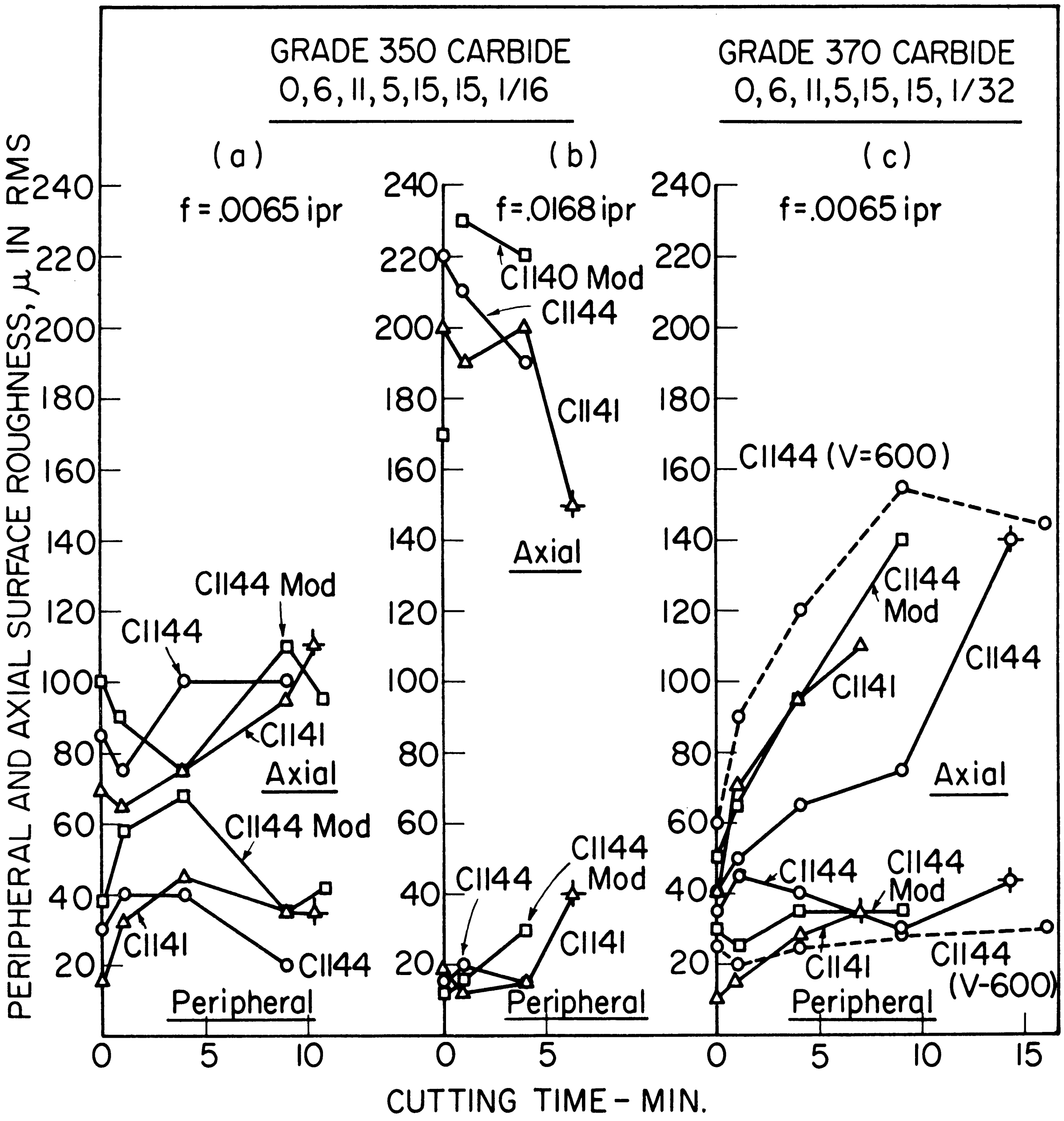


Fig. 14. Surface roughness vs. time on hot-rolled materials with carbide tools. V = 900 fpm (except as indicated for C1144 in (c)). Depth of cut, 0.070 in.; feed, carbide grade; and tool shape as indicated. Curves plotted from results in Table V. C1144 at 600 fpm and C1144 modified at 900 fpm in (c) gave comparable tool wear in same time interval.

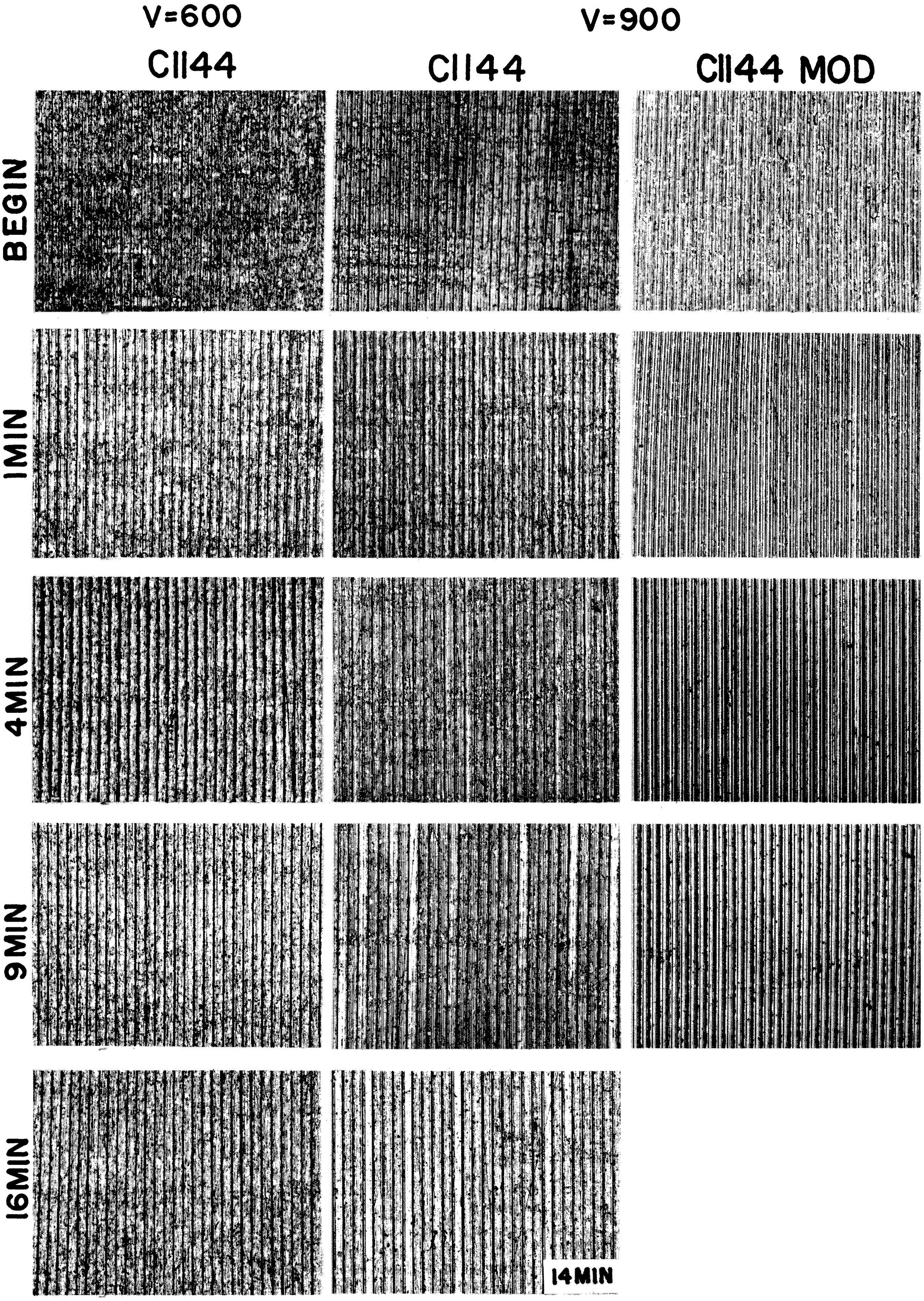


Fig. 15. Fax film reproductions of surfaces of the C1144 steels under conditions and values represented in Fig. 14c.

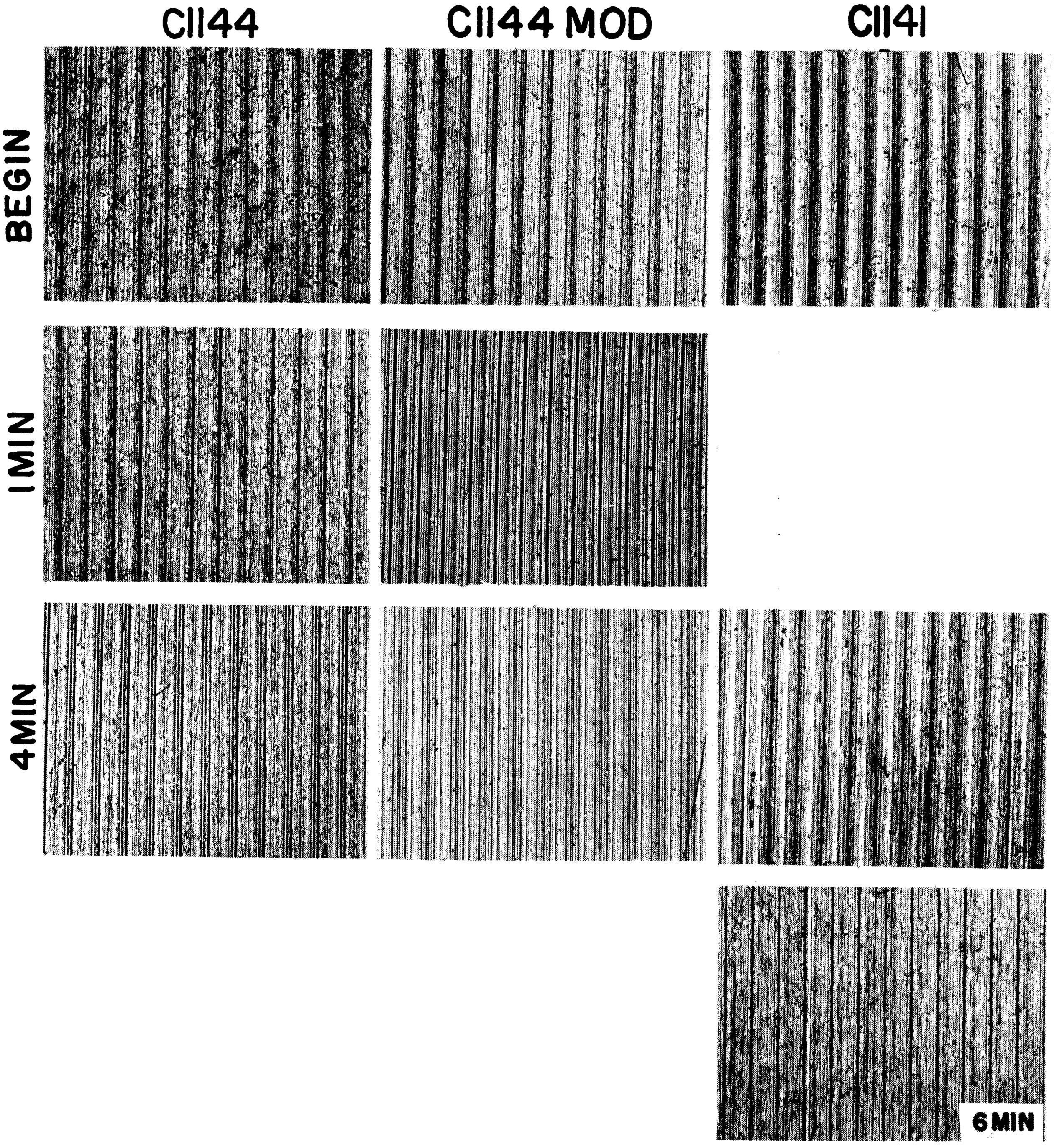


Fig. 16. Fax film reproductions of surfaces on hot-rolled materials under conditions and values represented in Fig. 14b.