THE UNIVERSITY OF MICHIGAN

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Final Report

GENERAL MACHINABILITY STUDIES ON THREE GRADES OF STAINLESS STEEL

Part II

AUTOMATIC SCREW MACHINE

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ABSTRACT

Extensive tests on an automatic screw machine were made in comparing tool-wear characteristics, feeding forces, surface quality, power requirements, and dimensional stability of the work materials. In general, the MA grade performed as well as, and in some respects better than, the M material.

The 18-8 required the highest forces in cutting and in most cases this difference was substantial.

OBJECTIVE

The purpose of this investigation was to analyze the machining behavior of the different grades of stainless steel under conditions similar to those occurring under production runs.

INTRODUCTION AND GENERAL CONCLUSIONS

The short sharp-tool tests, which have been reported in Part I, have revealed some significant facts about the relative performance of each grade of material. Tests of this nature do not always indicate how a material will behave under prolonged cutting. Tool wear may give rise to changes in, for example, cutting forces, dimensional stability, power requirements, and surface quality. An extensive test which permits relative evaluation of these factors is desirable since any one or combination of them may be used as a criterion of tool failure. Tests on a Brown and Sharpe automatic are useful for this purpose. The general conclusions are:

1. From the standpoint of an over-all performance, the MA grade exhibited the best machining behavior.

2. The machining of the 18-8 was generally the most difficult.

THE MATERIALS INVESTIGATED

Part II of the test program was composed of two phases:

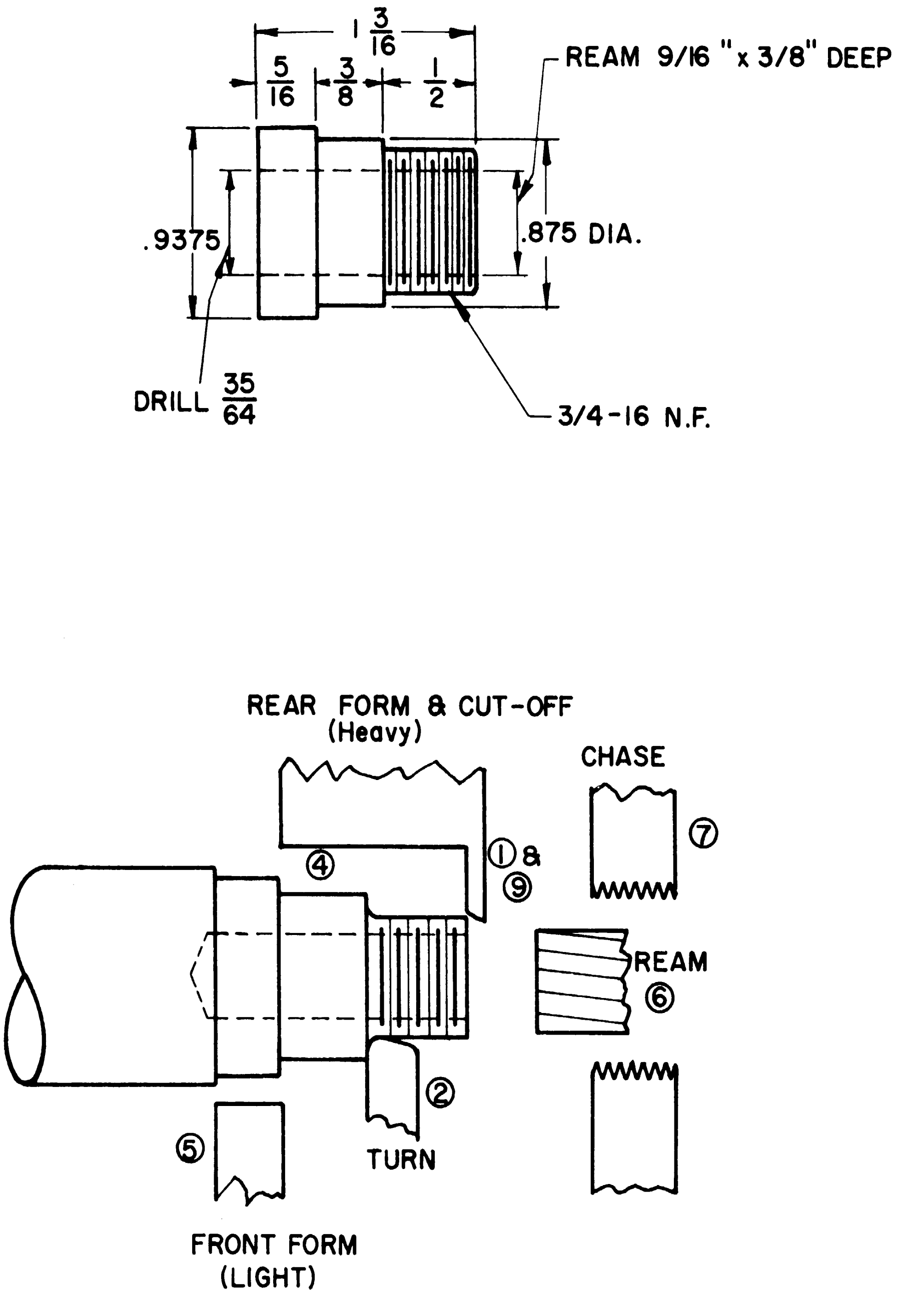
1. The material (annealed) used for Phase 1 was the same as used in Part I. The stock was centerless ground to 63/64-in., and coded as 18-8, 18-8M, and 18-8MA.

2. For Phase 2 the material (cold-worked) was received centerless ground to a 1-in. diameter, and tagged 303MA (yellow) and 303 (red). The designation of 303MA was kept and 303 was coded 303M.

TEST SETUP

The shape and size of part and the operational sequence used in a Brown and Sharpe, No. 2G, single-spindle automatic screw machine are shown in Fig. 1. The part was designed to reveal information on six basic machining operations - light and heavy forming, turning, drilling, reaming, chasing, and cutoff.

Force dynamometers mounted on the front and rear slides recorded the feeding forces on the light- and heavy-form tools. Strain gages mounted on the follower arm of the turret slide measured the turning feeding force and drill thrust. The forces were recorded on Sanborn recorders. Power requirements were recorded on a Esterline-Angus wattmeter for the various machining operations.



Spindle Speed: 290 rpm - Time / Piece: 225 sec

1. & 9. Cut Off
2. Turn - 3/4 OD
3. Chamfer
4. Heavy Form - 7/8 OD
5. Drill - 35/64 Hole & Light Form - 15/16 OD
6. Ream
7. Chase
8. Stock Feed
9. & 1. Cut-Off

Fig. 1. Test piece and operational sequence.

OPERATING CONDITIONS

All test conditions are summarized in Table I. They remained constant for all the materials tested.

TABLE I

ALL CONDITIONS OF TEST

Machine: Brown and Sharpe, No. 2G, single-spindle automatic
Cutting Fluid: 10% Stuart's Thred Cut and Circo XXX straight oil
Materials Tested: 18-8, 18-8M, 18-8MA, 303MA, 303

Operation	Cutting Conditions		Feed, in./rev.	Cutting Tools	
	Spindle Speed, rpm	Velocity, fpm		Material	Signature
Cutoff	290	75	.00125	*H.S.S.(Clarite)	10,0,6,2,10,-2,0
Knee Turn	290	75	.004	*H.S.S.(Mo-Max)	0,8,6,6,6,8,1/32
Chamfer	290	75	.0025	H.S.S.(Mo-Max)	0,0,0,6,0,30,0
Heavy Form	290	75	.00125	H.S.S.(Clarite)	10,0,6,0,0,0,0
Drill	290	41	.0033	H.S.S. Nat'l Twist Drill.Std. Screw Machine Oxide-Treated	118° Point Angle 15° Relief Angle
Front Form	290	75	.0005	H.S.S.(Clarite)	10,0,6,0,0,0,0
Ream	290	43	.009 (.0015/ blade)	H.S.S. Nat'l Twist Drill.Std. Machine Reamer	6 Blade Spiral Flute 45° Chamfer
Chase	290	57	.0625	Geometric H.S.S. Style 3/4 Milled	3/4-in.-16 N.F. 15° Hook Angle for Stainless Steel

* 18%W - 4%Cr - 1%Va.

TEST PROCEDURE

Each material was tested under identical tool setup and cutting conditions, and the length of a test was defined as 300 pieces for the 18-8MA, 18-8M, 303MA, and 303M. On the 18-8, the test was ended by complete failure of the turn tool.

The standard test procedure consisted of (1) properly setting all tools to produce parts within specifications; (2) machining of parts, with collections of all pieces in the exact sequence as produced by the machine; (3) recording light- and heavy-form feeding forces, turning tool feed force and drill thrust, and power requirements at intervals of 15 pieces; and (4) periodic visual inspection of the cutting tools during the run, with final inspection at the end of the test.

All surfaces on each part were inspected visually for significant changes in surface appearance. In addition, surface-roughness measurements were made on the formed surfaces with a Micrometrical Profilometer, and the same diameters were measured with a micrometer to record the dimensional change over the life of the test.

The results of the foregoing are plotted and shown under "Test Results."

Visual inspection was the only observation made of the threads, cutoff surfaces, and the drilled and reamed holes.

TABLE II

FORCES, SURFACE ROUGHNESS, DIMENSIONAL CHANGE

Mat'l	Force - lb				Surface Roughness μ - rms		Dimension Change (in.)	
	Light Form	Heavy Form	Turn	Drill	Light Form	Heavy Form	Light Form	Heavy Form
18-8	Max.-176.0 Min.-147.2 Ave.- *(1) 154.0 (2) 166.0	Max.-512.6 Min.-450.0 Ave.-481.3	Max.- (1) 1150.0 (Tool Failure) (2) 586.5 Min.- 362.3 Ave.- *(1) 391.0 (2) 431.3	Max.-1380.0 Min.-1207.5 Ave.-1265.0	20	12-22	0.003	0.007
18-8M	Max.-126.0 Min.- 80.0 Ave.-118.0	Max.-297.5 Min.-250.0 Ave.- *(1) 256.3 (2) 283.5	Max.- 316.5 Min.- 253.0 Ave.- 287.5	Max.- 868.0 Min.- 747.5 Ave.- 805.0	100-130	*(1) 140-180 (2) 80-120	0.002	0.002
18-8MA	Max.-115.2 Min.- 88.8 Ave.-106.0	Max.-275.0 Min.-235.0 Ave.-243.8	Max.- 299.0 Min.- 241.5 Ave.- 270.1	Max.- 793.5 Min.- 701.5 Ave.- 728.3	130-150	120-160	0.0012	0.0021
303MA	Max.-134.4 Min.-108.0 Ave.-116.0	Max.-312.5 Min.-287.5 Ave.-297.5	Max.- 323.5 Min.- 281.8 Ave.- 304.8	Max.- 897.0 Min.- 793.5 Ave.- 851.0	60-70	70-100	0.001	0.003
303M	Max.-157.6 Min.-124.0 Ave.-138.0	Max.-307.5 Min.-262.5 Ave.-281.5	Max.- 345.0 Min.- 299.0 Ave.- 330.6	Max.- 828.0 Min.- 690.0 Ave.- 709.3	120-140	*(1) 40-80 (2) 70-120	0.0017	0.004

* Represents 2 distinct levels.

TABLE III

TOOL WEAR - ALL MATERIALS

Tool	18-8	18-8MA	18-8M	303MA	303M
Turn	Tool failed at 195 pieces. Failure on flank at the intersection of OD and cutting edge. .0081 reading-wear. Very slight evidence of built-up edge.	.0095 radius wear and chipped. Flank edge— .024 smear region on flank. Regular wear of smear pattern of .009 to .013. Built-up edge very noticeable.	.007 radius wear and chipped. .002 regular wear pattern on flank. Slight evidence of built-up edge.	.0096 radius wear and/or smear. Even wear pattern on flank of .002. B.U.E. not measurable.	.0062 radius wear small chipped area on flank of .0035. No other wear on flank detectable. No B.U.E. discernible.
Heavy Form	.0034 wear in a very even pattern. Very slight evicence of built-up edge.	.0033 wear and/or smear. Chipped edge of .001. Built-up edge predominant at .008.	Regular wear pattern max. being .0025 and smear in evidence. .0059 corner wear. Slight evidence of built-up edge.	Even wear pattern on flank of .0028. .007 corner wear .0055 B.U.E. directly above corner wear.	.0038 wear near center of tool. Other wear even at .002. B.U.E. of .0032 on corner only.
Light Form	Even wear pattern of .0034. No evidence of built-up edge.	.0035 wear and/or smear. Built-up edge .0035.	.003 wear and/or smear. Built-up edge of .002.	Even wear pattern on flank of .0036. Corner wear .016. Spotty B.U.E.-max. .0036 at corner.	Regular wear pattern of .0037 on flank. Corner wear of .008. B.U.E. uniform at .0022 across cutting edge.
Drill	.005 max. wear. Smear and/or wear on corner of .0168. Chisel edge chipped badly.	.0057 max. wear and/or smear. Corner smeared heavily. Large built-up edge in area of chisel edge. Chisel edge chipped.	.007 max. wear and/or smear. Corner smeared heavily. Large built-up edge at chisel edge.	.008 max. wear and/or smear. Large B.U.E. at chisel edge. (≈.024) of 2 segments adjoining each cutting edge.	.006 max. wear and/or smear. Large B.U.E. at chisel edge of ≈.021 of 2 segments adjoining each cutting edge. Heavy smear on corners and margins.

TABLE III (Concluded)

Tool	18-8	18-8MA	18-8M	303MA	303M
Cutoff	.010 corner wear. Even wear pattern of .004	.0032 smear and/or wear. Built-up edge of .0085.	.0057 smear and/or wear. Built-up edge of .007.	.0015 wear and visible smear of .0045. Corner wear .005. B.U.E.-.0053.	.0016 wear and visible smear of .004 with even pattern.
Reamer	Wear of .0035 on corner of blade 4. All other corners less.	Wear and/or smear of .0118 on corner of blade 4. All others same condition but less in magnitude.	Wear or smear of .0126 on corner of blade 3. All other corners same condition but less in magnitude.	Approx. .020 wear and/or smear on blades 4, 5, and 6. Other blades ≈.0054.	Approx. .015 wear and/or smear on corner of blades 1, 2, and 6. Slight wear and/or smear on other blades.
Chasers	Chaser No. 3 max. corner wear of thread of .010. Heavy smear on chaser No. 4.	Chaser No. 1 max. smear and/or wear of .018. Max. built-up edge of .006 on first thread on chaser No. 1. Slightly less B.U.E. on first thread on the 3 other chasers.	Chaser No. 1 max. smear and/or wear of .015. Max. built-up edge of .006 on first thread on chaser No. 2. B.U.E. approx. same for other chasers.	No chasers used.	Chaser No. 1 max. smear and/or wear of .011. B.U.E. found on chaser No. 3 on threads 1 and 2 of approx. .004.

TEST RESULTS

LIGHT FORMING

Feeding force values and surface-roughness readings are plotted in Figs. 2 to 5 inclusive for the light-forming operation on each of the materials tested.

This operation most generally gave rise to discernible differences between the materials tested. The feeding force for the 18-8 was higher than either the 18-8M or 18-8MA, either in the annealed condition or cold-worked. The 18-8MA (and 303MA) exhibited the lowest forces, whether annealed or cold-worked. Referring to Figs. 3 and 4, the 18-8M and 303M exhibited slightly higher force readings and the trends of the slopes were consistently of a higher level.

Referring to Table III, tool wear for the form tool was very nearly the same for all the materials, as reflected in the relatively small differences in the forces produced by each material. This indicates the sensitivity of each material relative to tool wear; the 18-8MA and 303MA appeared least sensitive.

The surface quality obtained in this operation can be considered to be the predominant factor in evaluating the performance of the materials, especially between the MA and M grades. The 18-8 produced the best consistent surface finish, both by profilometer measurements and by visual comparison. The MA and M grades produced approximately the same level of quality with one exception described later. Referring to Figs. 2 and 5 and Table II, the general concept of higher force producing a better finish is substantiated with the 18-8M and 18-8MA materials. But contrasting the 303MA versus 303M, the quality of the 303M deteriorated considerably. The cause for this reversal is not fully understood, but it is interesting to note (with reference to Figs. 3 and 4) the trends of the force and surface finish readings. Apparently the built-up edge entered quite significantly in producing a poorer finish. It is significant to note in Table III the extent and pattern of B.U.E. on the tools. The character of the B.U.E. was affected by cold-working the material (303MA and 303M), which substantially improves the surface finish of these grades.

HEAVY FORMING

Figures 6 and 7 represent the results of feeding force and surface-roughness for the heavy-forming operation on each of the materials. The results are quite similar to those obtained for the light-forming operation. The most

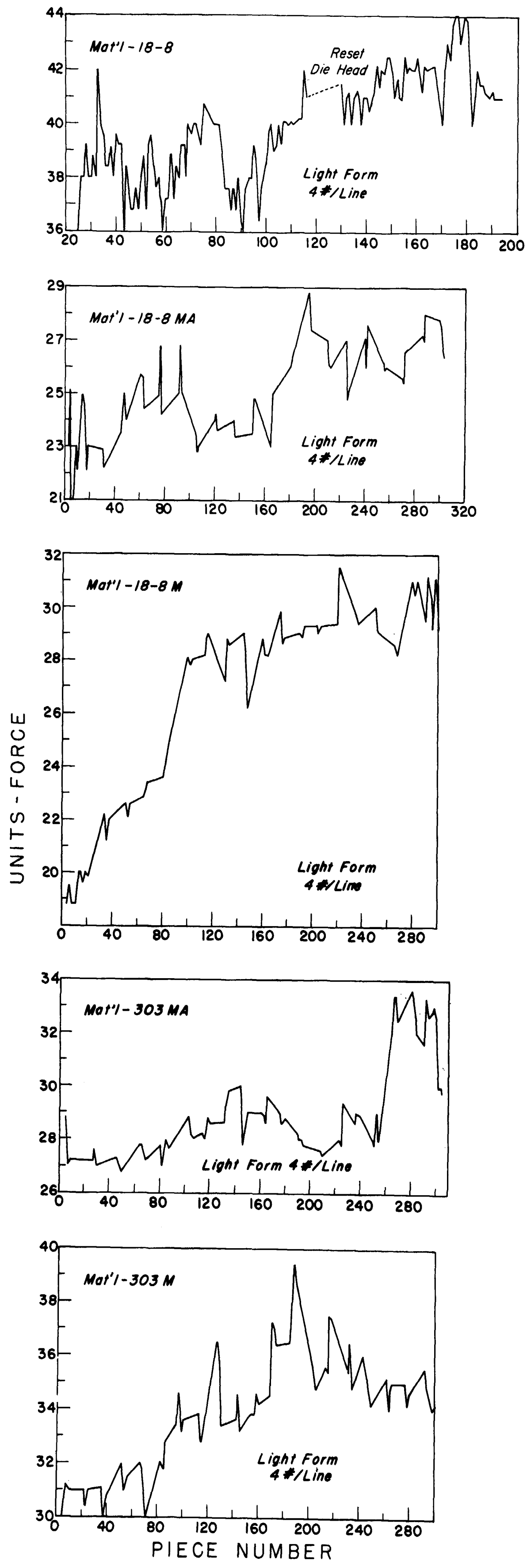


Fig. 2. Units-force vs. piece number.

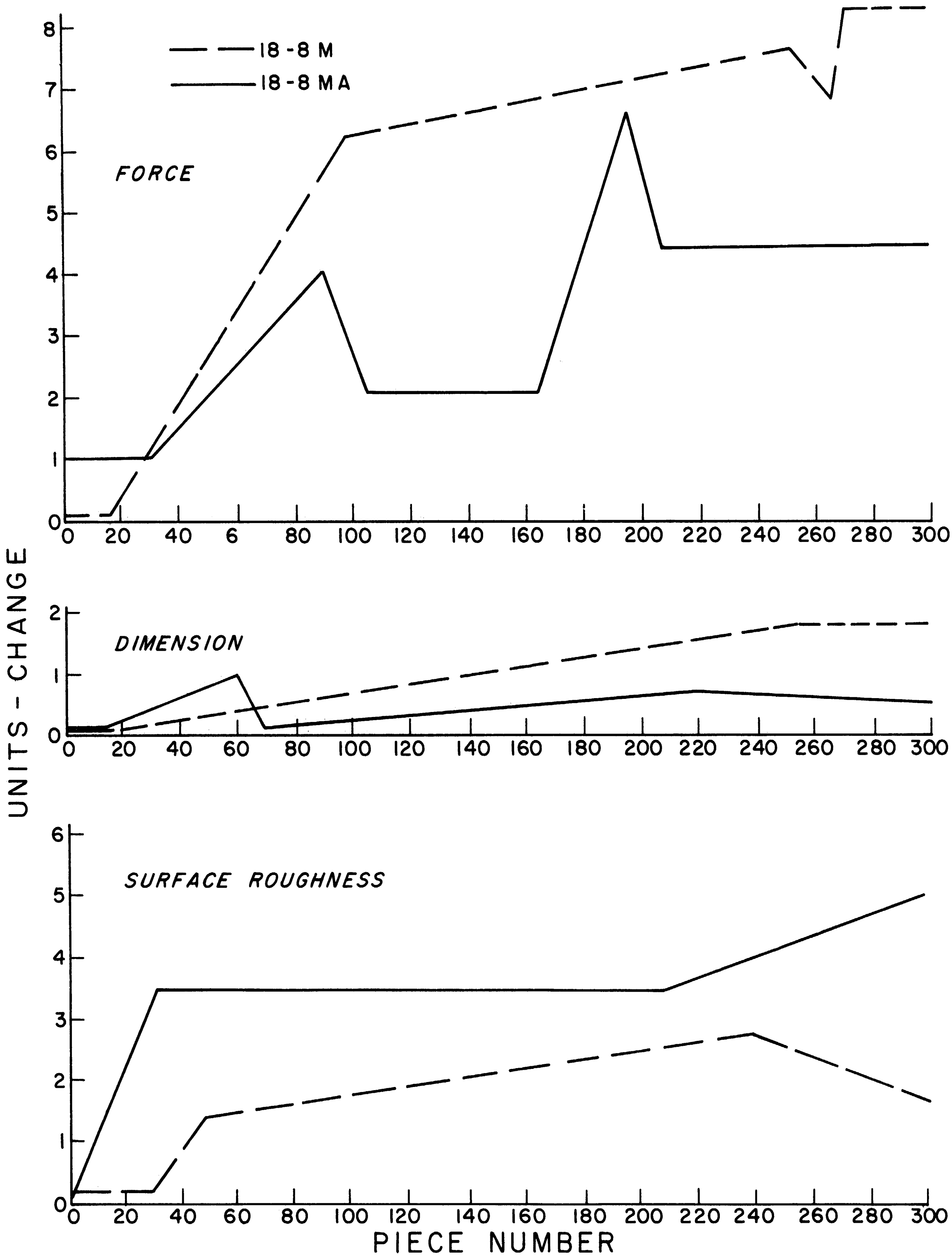


Fig. 3. Trends of slopes.

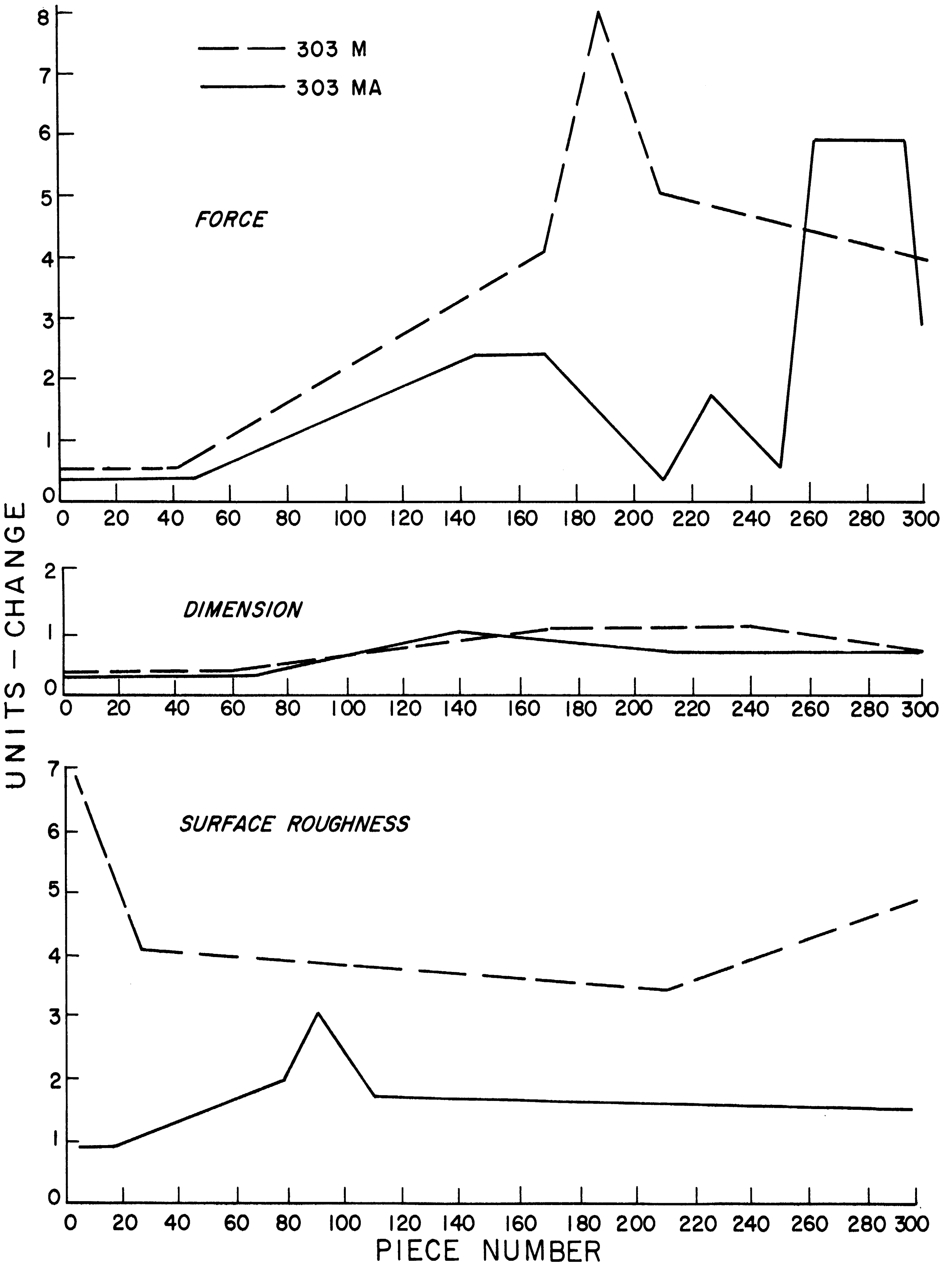


Fig. 4. Trends of slopes.

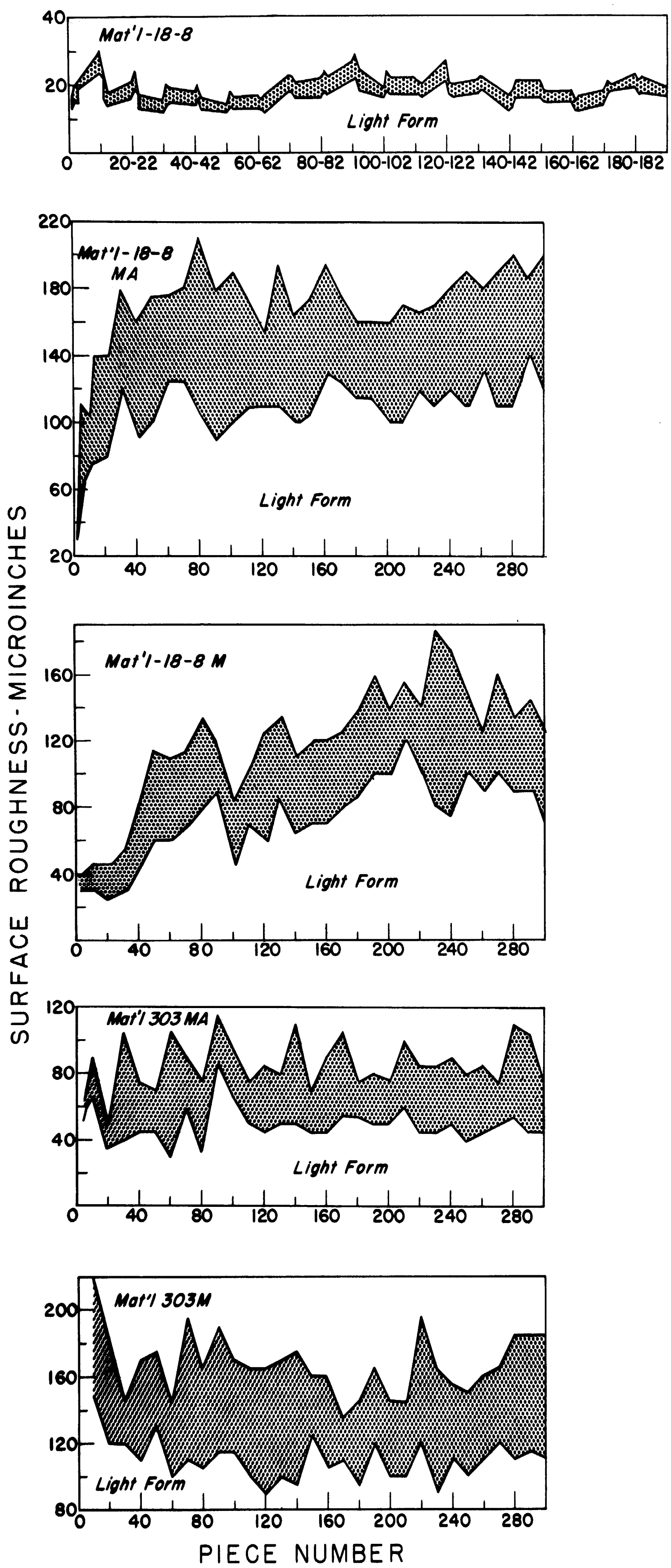


Fig. 5. Surface roughness vs. piece number.

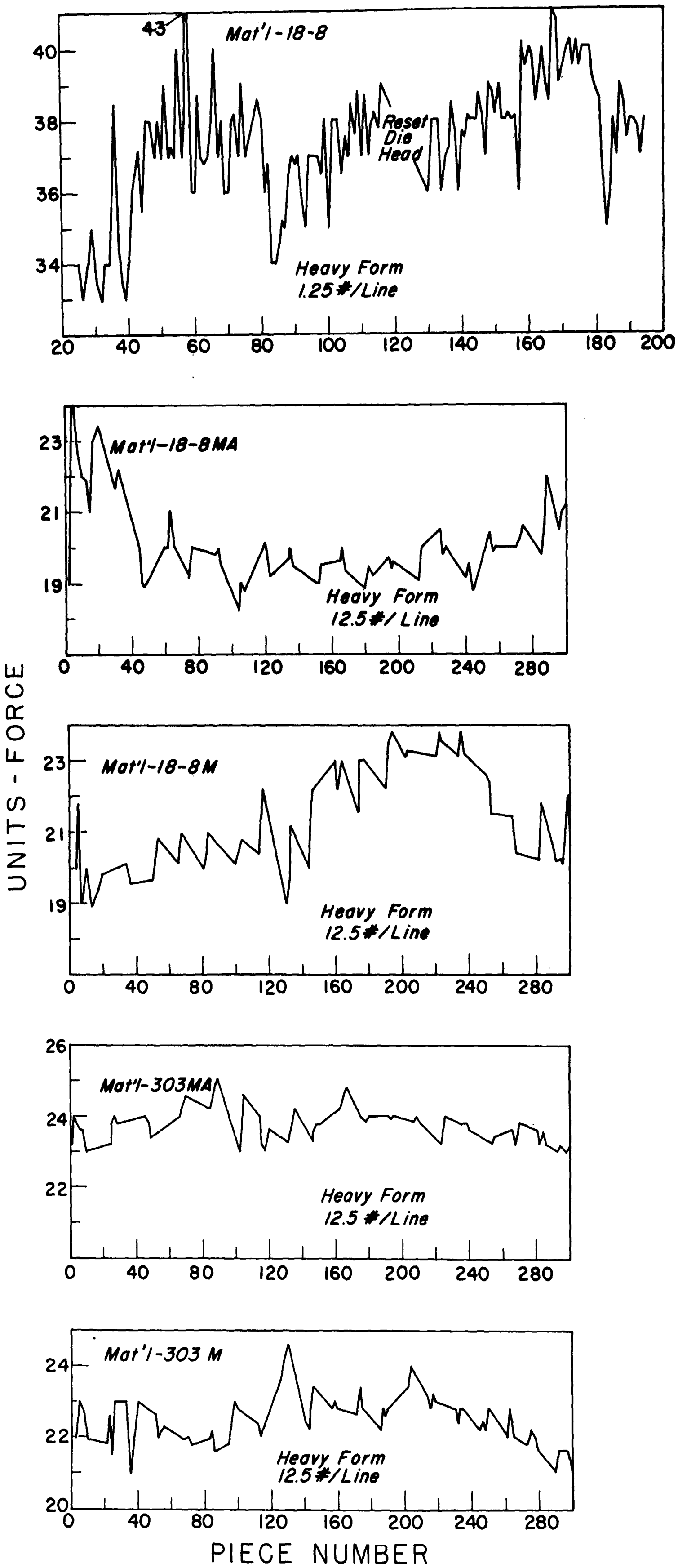


Fig. 6. Lines deflection vs. piece number.

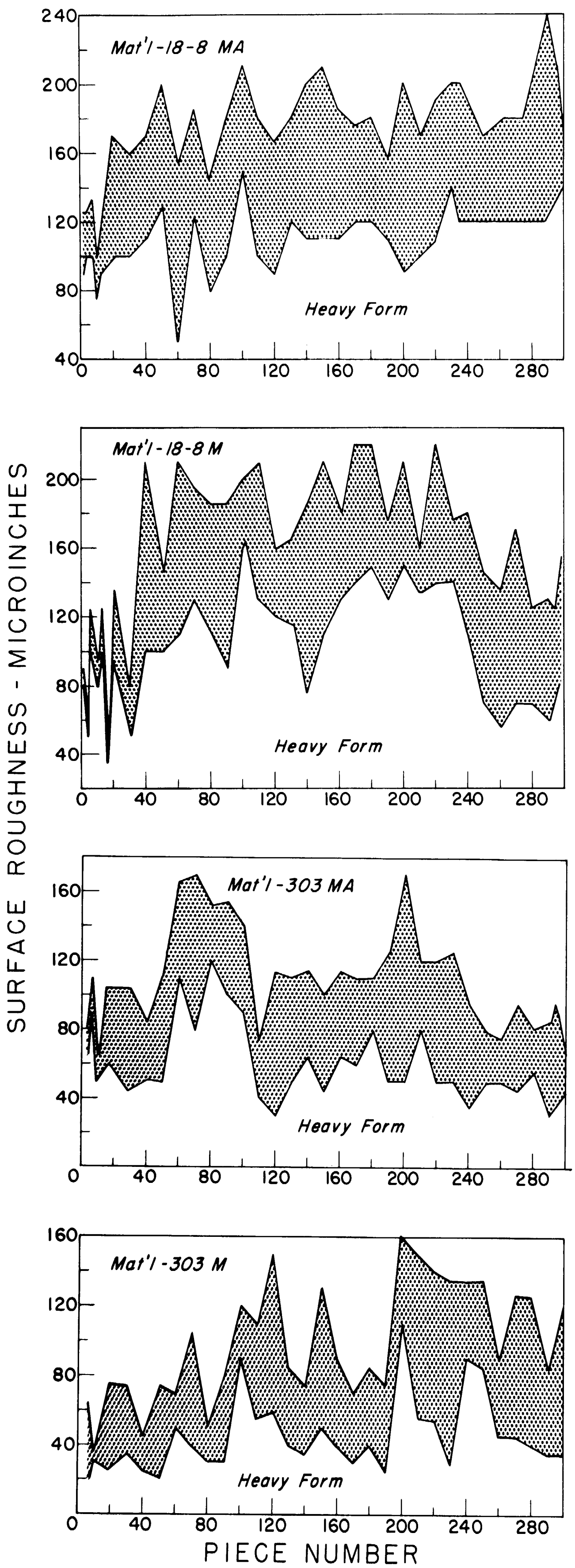


Fig. 7. Surface roughness vs. piece number.

pronounced differences appear in the magnitude of the forces recorded. Referring to Table II, the force for the 18-8 is approximately two times greater than that for the 18-8MA or the 18-8M, and slightly less than two times greater than the force produced on the 303MA and 303M.

Tool wear for the heavy-form tool was very similar in magnitude for all the materials, indicating the sensitivity of the materials relative to tool wear in affecting the feeding force.

The surface quality obtained on the materials with this forming condition is in line with the quality produced by the light-forming condition. On the 303MA and 303M grades, cold-working the material improves the surface quality significantly.

TURNING

Figure 8 shows the feeding-force results for the turning operation for each material.

The forces recorded for the materials closely follow the pattern established for the light-forming operation. The 18-8MA and 303MA have lower force values than the M grade materials, whether annealed or cold-worked, with no tendency to increase as the test progresses.

Referring to Table III, the built-up edge is very prominent for the 18-8MA and 18-8M materials, but not present on the 18-8, 303MA, and 303M grades. This corroborates that the presence, amount, and stability of the B.U.E. exerts a predominant role in the resulting surface quality.

DRILLING

The thrust force of the drill is the largest of all the forces measured in the test runs. The values are in agreement with the trends as produced by the other operations.

The surface quality of the drilled hole was much better for the 18-8 than the other materials, compared visually. The finish for the cold-worked MA and M was somewhat better than the annealed grades. Whether the MA and M were annealed or cold-worked, no definite distinction could be made between the quality of the drilled holes.

CHASING

Thread surface quality was good on the 18-8, and the finish for the other grades was much lower in quality. No distinction could be made among the MA or M materials.

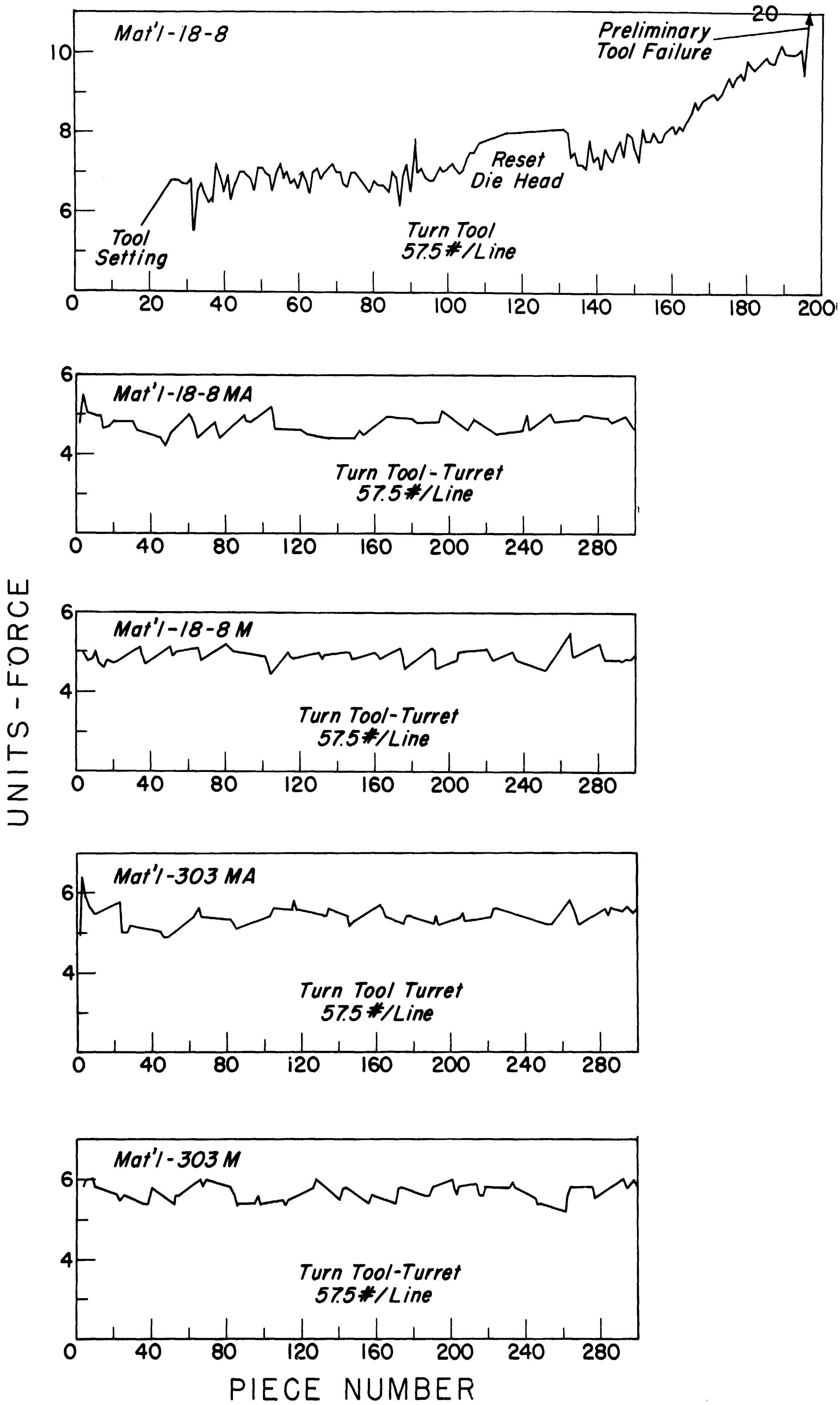


Fig. 8. Units-force vs. piece number.

Size was difficult to maintain for a class 3A thread in the 18-8 material, but the other materials presented much less of a problem in attempting to hold the thread tolerance over the entire run.

SPECIFIC CONCLUSIONS

1. 18-8MA, 303MA versus 18-8M, 303M.

   (a) The MA and M grades produced forces of approximately the same magnitude.

   (b) The 303MA produced a significantly better surface quality on the light-form operation, while, on the heavy form, finishes of similar quality were produced for both materials.

   (c) The MA material on the average produced lower dimensional variation.

   (d) Built-up edge was generally less for the 303MA.

   (e) From the standpoint of general machining characteristics (chip handling, vibration, etc.), the MA and M materials were good.

   (f) There was no large amount of wear present on the turn tools of the above materials after approximately 18-1/2 hr of actual cutting time.

2. 18-8 versus all other grades. A superior surface quality was consistently produced on the 18-8 material for all operations.

   (a) Forces were always substantially higher for the 18-8.

   (b) The dimensional change for the 18-8 was fairly pronounced. Accuracy was difficult to maintain in the chasing operation.

   (c) Tool failure occurred on the 18-8 turn tool at approximately 12 hr of actual cutting time.

   (d) The general machining characteristics of the 18-8 was only fair compared to the other materials. Chip handling was difficult, and vibrations(chatter) were always present, though not to a large degree.