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DEBURRING BY CENTRIFUGAL BARREL TUMBLING

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Project Leader:
L. K. Gillespie
Department 822

Project Team:
B. J. Neal
R. L. Kirkpatrick
C. E. Roebuck

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DISCLAIMER

DEBURRING BY CENTRIFUGAL BARREL TUMBLING

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Prepared by L. K. Gillespie, D/822, under PDO 6984405

The reliability of small precision mechanisms greatly depends upon the production of burr-free, sharp-edged parts. Centrifugal barrel finishing (Harperizing) is one of the few processes capable of producing these conditions. Burrs less than 0.001 inch thick by 0.001 inch high (25.4 x 25.4 μm) can be removed from 303 Se stainless steel, 1018 steel, and 6061-T6 aluminum with dimensional changes in the order of 0.0001 inch (2.54 μm) and final edge radii of 0.003 inch (76.2 μm). These conditions can be produced in batch lots in 20 minutes or less. Surface finishes can be reduced from 45 to 25 or 35 microinches (1.15 to 0.68 or 0.89 μm), with 60 minute cycle times. Stock losses appear to be repeatable within ±0.00006 inch (1.524 μm). Very small parts receive less action than parts 0.5 inch (12.7 mm) in diameter.

WPC-sp

THE BENDIX CORPORATION
KANSAS CITY DIVISION
P.O. BOX 1159
KANSAS CITY, MISSOURI 64141

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SUMMARY

Component parts of small mechanisms need near-sharp edges to be reliable; parts must also be burr free to avoid jamming the mechanism if burrs should break loose during operation. In the past machining burrs have been removed by hand because of these needs, but hand deburring is time-consuming and inherently operator-variable.

This study was initiated to determine how centrifugal barrel tumbling affected the surface finish, edge radius, and dimensions of precision miniature piece parts. The study involved 5800 measurements on both test specimens and actual production parts.

For normal conditions, burrs 0.001 inch thick by 0.001 inch high (25.4 by 25.4 μm) were removed in 2 to 5 minutes. Thicker and higher burrs required much longer times. It is possible to remove burrs 0.001 inch or less while removing only 0.0001 inch (2.54 μm) from external surfaces. For smaller burrs, complete burr removal can be obtained with stock losses of 0.000050 inch (1.27 μm) or less. The repeatability (standard deviation) of stock loss on many samples was within 0.000020 (0.51 μm).

Nominal edge radii of 0.003 to 0.005 can be easily produced with this process, but smaller radii can be produced only when burrs are 0.001 inch thick or thinner. Typical burrs found on miniature parts produced from 303 Se stainless steel, 1018 steel, and 6061-T6 aluminum are 0.003 inch thick by 0.003 inch high (76.2 by 76.2 μm).

For the conditions studied in this test, surface finishes improved from 45 microinches (1.15 μm) to 25 microinches (0.68 μm). Surface finish and radius changes are exponential functions of time, while stock losses are typically linear. High velocity (high g levels) increases abrasive action greatly, as does the use of large media.

The effectiveness of deburring is an exponential function of burr thickness and running time. Thick burrs are removed much slower than thin burrs. While the process is fast, works well on miniature parts, and is very repeatable, the conditions used must be carefully matched to part geometry, size, and material. Very small parts receive much less action than larger parts.

DISCUSSION

SCOPE AND PURPOSE

The objective of this study was to determine how centrifugal barrel tumbling affected edges, dimensions, and surface finish, and how burr size affects the results.

PRIOR WORK

No prior studies of centrifugal barrel tumbling have been reported by Bendix, although three related studies have been reported on vibratory deburring.[1,2,3]

ACTIVITY

Centrifugal barrel tumbling, as the name implies, is the process of allowing parts to tumble in a rotating barrel under a centrifugal force. A centrifugal barrel unit is much like a ferris wheel, except the barrels rotate in the opposite direction of the outer portion of the machine (Figure 1). The rotation of the turret to which the drums are attached creates the centrifugal force. The barrel rotation produces a continuous sliding action of parts and abrasive within each barrel.

Like all loose abrasive deburring operations, parts are mixed with loose abrasive particles, an abrasive compound, and water. The particles, which are much like sand pebbles, flow over part surfaces removing burrs and polishing the surfaces. Some typical particles used on precision miniature parts are shown in Figure 2. Precision as used here indicates that piece part tolerances are less than 0.002 inch (50.8 μm). Miniature is used to indicate that the largest piece part dimension is less than 1 inch (25.4 mm). The majority of parts and applications described in this report are for parts roughly 0.25 inch (6.35 mm) in size or smaller having at least one tolerance less than 0.001 inch (25.4 μm). These abrasive particles are available in over 500 combinations of sizes, shapes, materials, and degrees of aggressiveness.

This process has several advantages over other processes for deburring precision miniature parts.

- It is a mass finishing operation (that is, it deburrs many parts in a single cycle).
- It has very short cycles (10 to 20 times faster than vibratory deburring).
- It is specifically designed for small parts.

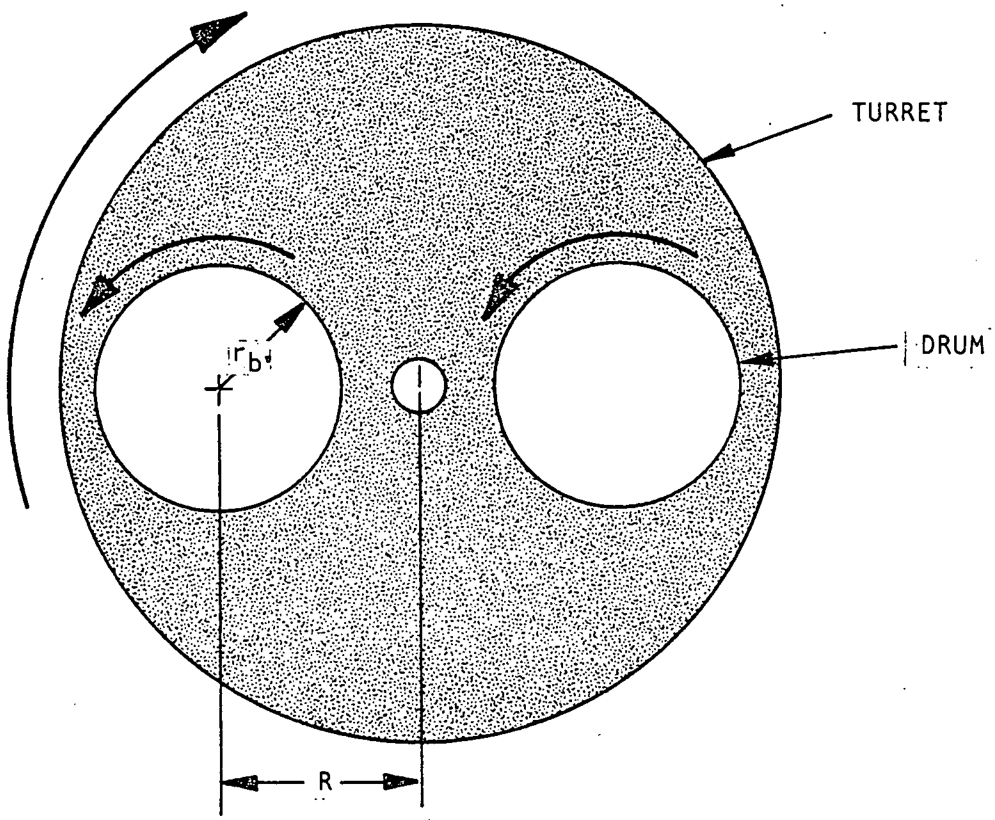


Figure 1. Schematic of Centrifugal Barrel Finishing Unit

- It is a very flexible process (easily adaptable to different part shapes, sizes, and tolerance restrictions).
- It cleans and polishes while removing burrs.

General Test Details

Three basic tests were performed in this study. In the first, changes in diameter, surface finish, and edge radius were monitored for seven different conditions, three part sizes, and three workpiece materials. In the second test, the repeatability of size change was evaluated for two materials. In the third test, an attempt was made to quantitatively evaluate how burr size influences the edge radius produced.

In all tests a model 2VM-13 centrifugal barrel tumbling machine (Harper Buffing Machine Company, East Hartford, Connecticut) was used. Although Soviet, Japanese and other manufacturers have recently been introduced commercially, centrifugal barrel tumbling is often called Harperizing because the process was developed by and the majority of units available in the United States were

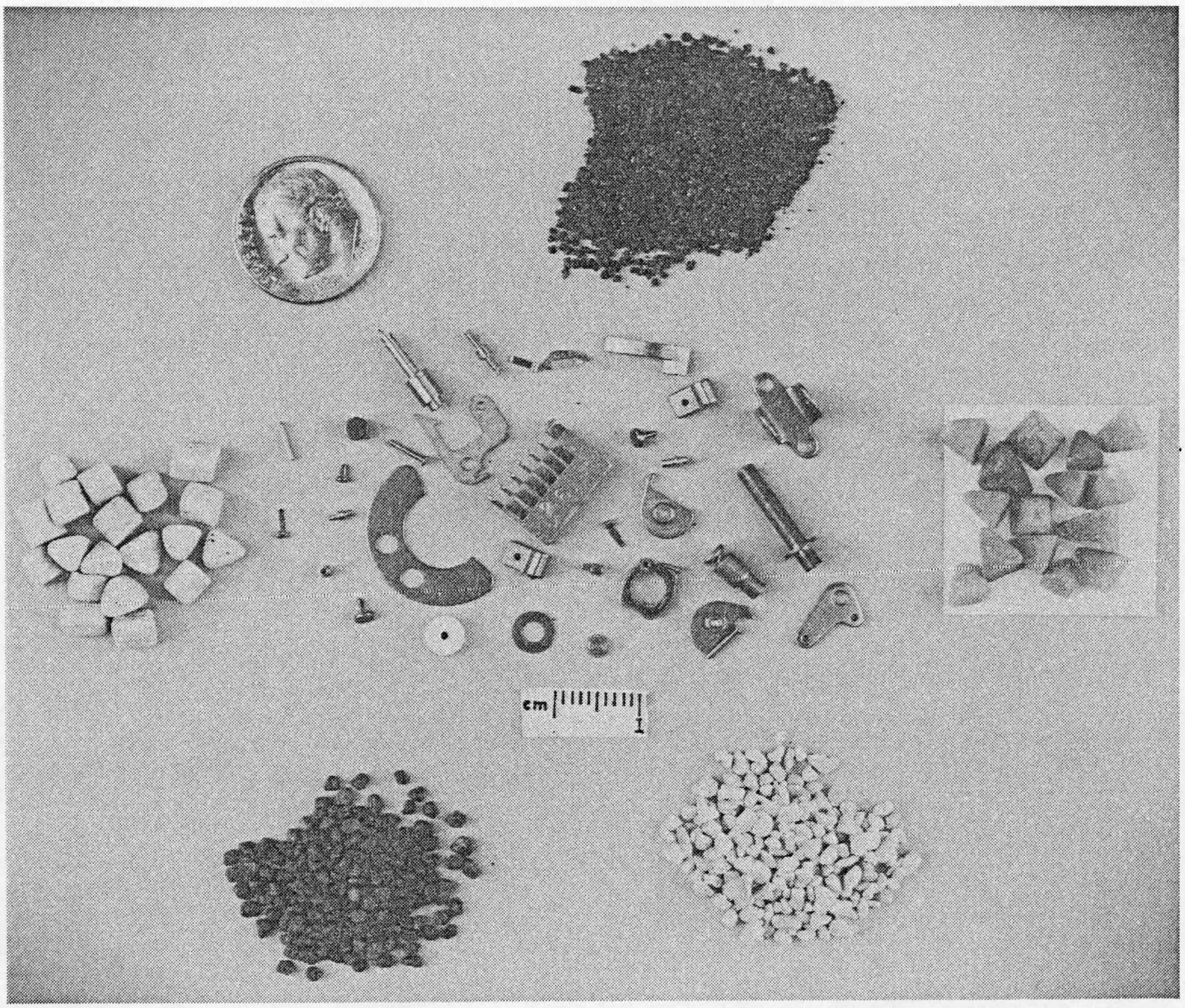


Figure 2. Typical Particles Used on Precision Miniature Parts

produced by the Harper Buffing Machine Company. The term Harperizer will be used in this report synonomously with centrifugal barrel tumbling. This machine is horizontally mounted and utilizes 13-inch-diameter (330 mm) barrels. These barrels hold 2 quarts (2.2 liters) of abrasive particles (media) and typically up to 1 quart (1.1 liter) of parts. As seen in Figure 1, the machine has two barrels located at distance "R" from the center of the turret. The distance R for this machine is 12 inches (305 mm). Centrifugal force is expressed by:

$$F_{CENT} = \frac{mV^2}{R} = \frac{4WR\pi^2n^2}{3600g} \qquad (1)$$

where

m = Mass (mass of all objects in barrel in this case);

V = Velocity of center of barrel;

F = Centrifugal force;

R = Radius of rotation;

W = Weight (of contents of barrel in this case);

n = Number of revolutions; and

g = Acceleration of gravity.

In the English system of units where W is in pounds, R in feet, and n in RPM, Equation 1 reduces to

$$F_{CENT} = 0.000341\ WRn^2 \tag{2}$$

For a radius of 12 inches (305 mm), a barrel content weight of 10 pounds (ten percent of which is assumed for illustration purposes to act on the parts), a speed of 209 RPM, the parts in the machine are subjected to a 15 pound grinding and deburring force.

For ease of calculation and machine control the force level is generally described in terms of "g" forces (i.e., the force is "X" times larger than the force of gravity). Thus,

$$F_G = \frac{mV^2}{R} \quad \frac{1}{m/g} = \frac{V^2 g}{R} \tag{3}$$

$$= 0.000341\ Rn^2 g \text{ (in English system of units).} \tag{4}$$

where F_G is a number representing how much larger the force is than the force of gravity. For the values given above, the machine produces a force of 15 g's. Throughout the remainder of this report forces will be described in terms of g forces.

The above analysis is only approximate, because it is based on the center of the barrel and the parts and media slide along the inside diameter of the barrel, a distance r_b from the center. Matsunaga[4,5,6] has developed more accurate equations to describe actual forces and motion of the parts. Because each model of centrifugal barrel units has different values of R and r_b, the results of the studies in this report will not exactly reflect the results to be found in other machines.

Basically, the machine was operated by placing 2 quarts (2.2 liters) of abrasive media in each barrel, adding a cup of abrasive compound, inserting parts, and covering the entire mixture with water. After running for a specified time (20 minutes unless otherwise noted) the barrel was flushed with clean water, a burnishing powder was added, the machine was cycled for an additional 5 minutes, and then rinsed. Parts were then separated from the media. More complete details of the procedure used are given in Bendix Process Engineering Specification (PES) P-1251048. The media and abrasive compounds used are described in detail in Appendix A of this report.

Effects of the Process on Edge Radius, Size, and Surface Finish

In this test, solid cylinders of 1018 steel (R_B93), 303 Se Stainless Steel (R_C21), and 6061-T6 aluminum (R_B60) were subjected to various combinations of media and g forces. The edge radius, change in diameter, and surface finish were recorded five times in a total deburring cycle of 60 minutes. Each time the specimens were reinserted in the barrels, the barrel was flushed and fresh abrasive compound was added. Table 1 indicates the three sizes of specimen used. The diameter of each specimen was measured to the nearest 0.000020 inch (0.508 μm). To assure close uniformity, all specimens were originally centerless ground to ±0.0001 inch (±2.54 μm) and cut to length in a monoset tool grinder using a 0.015 inch (381 μm) thick abrasive cut-off wheel. This wheel typically produced burrs of the size shown in Table 2. Most screw machines as used at Bendix produce burrs of this same size. Most machining processes produce burrs two to three times larger than these values. The definition of burr properties is shown in Figure 3.

Ten specimens were used of each specimen material and each size in each of seven tests. Edge radii and burr size were recorded to the nearest 0.0001 inch (2.54 μm) using a Leitz optical measuring machine. Surface finish was recorded to the nearest microinch. The results of these measurements were averaged and this average was used to plot the curves shown in Figures 4 through 24. Note that two readings of edge radius were taken on each part which provided 20 readings at each combination. Media sizes used are shown in Figure 2 and described in detail in Appendix A. Initial burr height is plotted as a negative radius in Figures 4 through 24.

As seen in Figures 4 through 24, edge radius increases with time in an exponential fashion. In the majority of cases edge radii do not exceed 0.010 inch (254 μm) after 60 minutes. A 0.005 inch (127 μm) radius occurs after roughly 20 minutes. Edge radii of only 0.002 inch (50.8 μm) can be produced after a 10 minute cycle under some conditions.

The large parts had larger radii than other specimens run under identical conditions. In Figure 4, for example, after 20 minutes

Table 1. Specimen Size

Diameter (Inch)	(mm)	Length (Inch)	(mm)
0.490	12.446	0.500	12.700
0.240	6.096	0.250	6.350
0.115	2.921	0.125	3.175

in N14 nuggets at 15 g's, the 1/8-inch (3.175 mm) specimen had a 0.003 inch (76.2 μm) radius while the 1/2-inch specimen had a 0.006 inch (152.4 μm) radius.

Diameter changes followed a similar pattern of size dependency. For the conditions just described, after 60 minutes the diameter of the largest specimen decreased 0.0008 inch (20.3 μm) while the small specimen lost only 0.0004 inch (10.15 μm). These stock losses were roughly linear with time.

As a general rule surface finishes improved from 40 microinches (1.016 μm) to 24 microinches (0.610 μm) in 60 minutes. Surface finish results, however, varied significantly with workpiece material and conditions used.

The aggressiveness of the Harperizing action was roughly proportional to the size of media used (Figure 25) and to the magnitude of the forces used (Figure 26).

By extrapolating the data, it appears that the burrs were entirely removed after roughly 2 to 5 minutes in the Harperizer. As indicated later, thicker and higher burrs require more time for complete removal. For such small burrs it is possible to assure complete burr removal with less than 0.0001 inch (2.54 μm) change in stock diameter. In some cases it is possible to assure 0.000050 inch (1.27 μm) or less size change.

The data in Figures 4 through 26 tended to be highly repeatable. Edge radii, for example, had a standard deviation of 0.0003 to 0.0006 inch (7.6 to 14.2 μm). Diameters had a standard deviation of 0.00002 to 0.0002 inch (0.5 to 5.1 μm). However, surface finish standard deviations varied from 3.0 to 13.0 microinch (0.0762 to 0.330 μm).

The data for radii in Figures 4 through 24, was fitted to a mathematical model

$$R = a_o + a_1 t + a_2 t^2 \qquad (5)$$

Table 2. Properties of Burrs Produced With Abrasive Cut-Off Wheel

Workpiece Material	Burr Size*			
	Thickness (Mil)	(μm)	Height (Mil)	(μm)
Aluminum				
0.5 Inch (12.5 mm)	1.2	(30.48)	2.3	(58.42)
0.25 Inch (6.35 mm)	1.3	(33.02)	2.3	(58.42)
0.125 Inch (3.175 mm)	1.3	(33.02)	1.6	(40.64)
1018 Steel				
0.25 Inch	0.9	(22.86)	0.7	(17.78)
0.125 Inch	0.2	(5.08)	0.3	(7.62)
303 Se Stainless Steel				
0.25 Inch	0.8	(20.32)	0.4	(10.16)
0.125 Inch	0.6	(15.24)	0.5	(12.70)

*Values shown are average readings.

where

R = edge radius and

t = time in Harperizer.

In fitting the data, an attempt was made to define the initial burr height as a negative radius. The fit was poor. The same is true when an initial radius of zero was assumed. The quadratic model has concavity either up or down when the plot of the data shows concavity to the right. The model

$$R = at^b \qquad (6)$$

using the negative radius when t = 0 was tried, also using R = 0 when t = 0. This gave very good results (the correlation coefficients were typically 0.97 or better). The burrs on these parts were relatively small and were removed rapidly. The predicted radius at the end of 1 minute exceeded the initial burr height. Had the burrs been large, their size would have had to be considered.

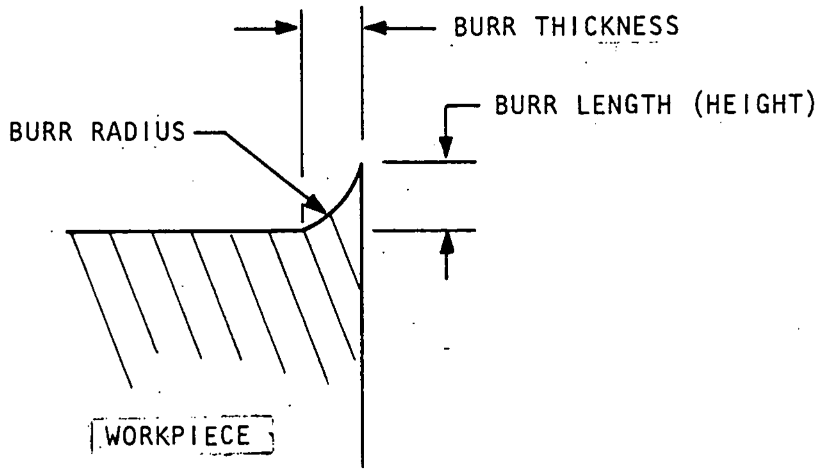


Figure 3. Cross-Sectional View of Typical Burr

Tables 3 through 5 gives the fitted equations for each process or group, material, and size. The standard error of the estimate σ_R is given for each. The burr at t = 0 was omitted for these calculations (that is, at t = 0, R = 0). This ficticious point was not used in computing σ_R.

The fitted equations for predicting the radius at time "t" minutes, are valid for time intervals of 0 to 60 minutes.

The data for the 20 and 40 minute intervals for Groups V and VII indicate possible errors in timing. The 20-minute time appeared to be more nearly 30 minutes and the 40-minute time probably was not run at all. The direct comparison of size and material effect within the group is still valid because they were all processed together. The standard error σ_R for Groups V and VII reflect these consistent shifts for 20 and 40 minute time intervals.

An estimate of the radius after 1.0 minute harperizing (t = 1) is the coefficient "a" in the above equations. Group III has the largest coefficients for all equations, indicating it is about twice as fast as Group I, two to three times as fast as Group II and about four times faster than Group IV in forming the radius.

A better estimate for the rate of change of radius per minute in the interval 0 to 60 minutes may be obtained from the derivative of the fitted equation

$$\frac{dR}{dT} = a\ b\ t^{b-1} \tag{7}$$

Text continued on page 43.

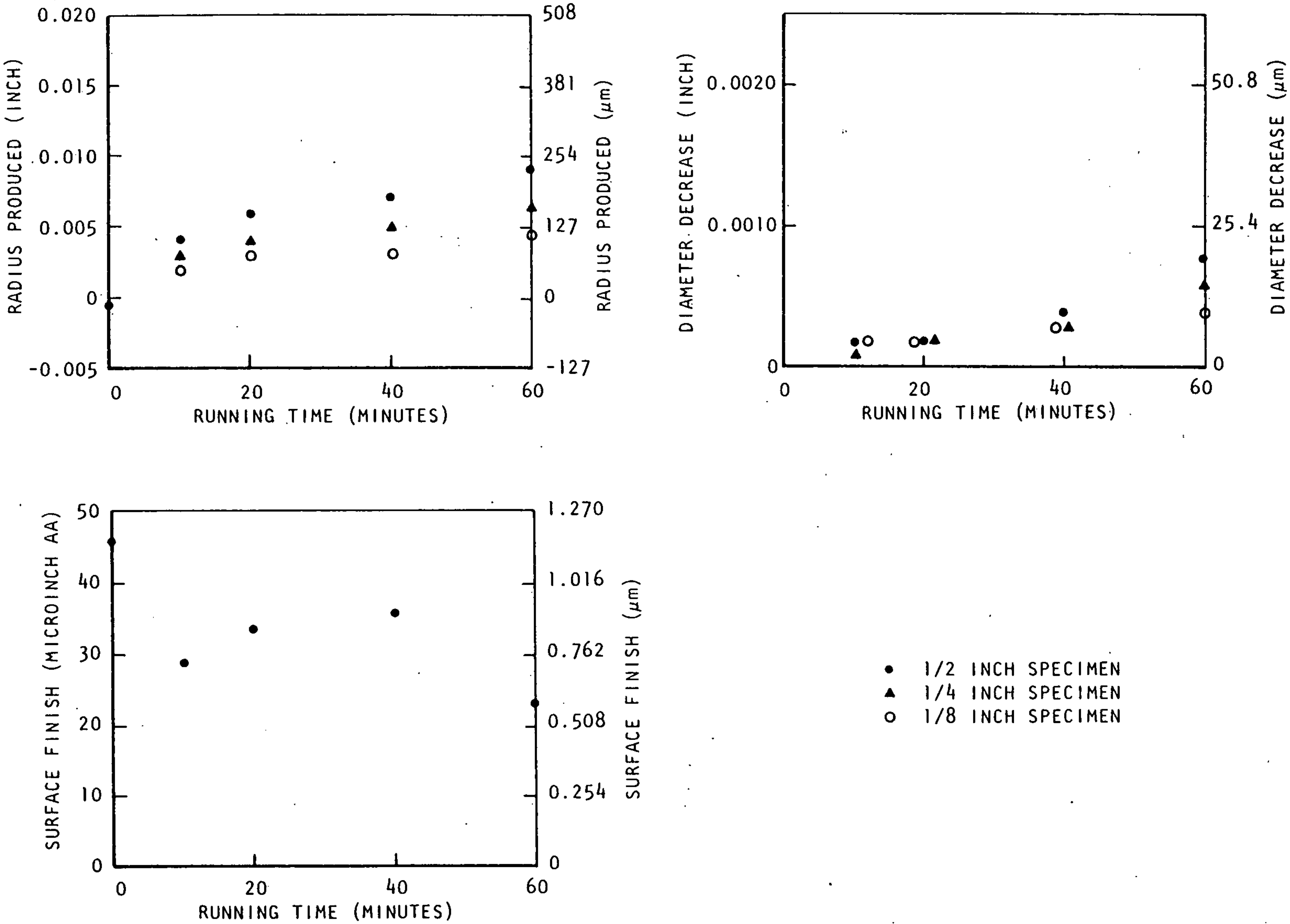


Figure 4. Harperizing Effects on 1018 Steel Cylinders, Using N14 Nuggets and 1A-1 Compound at 15 g's

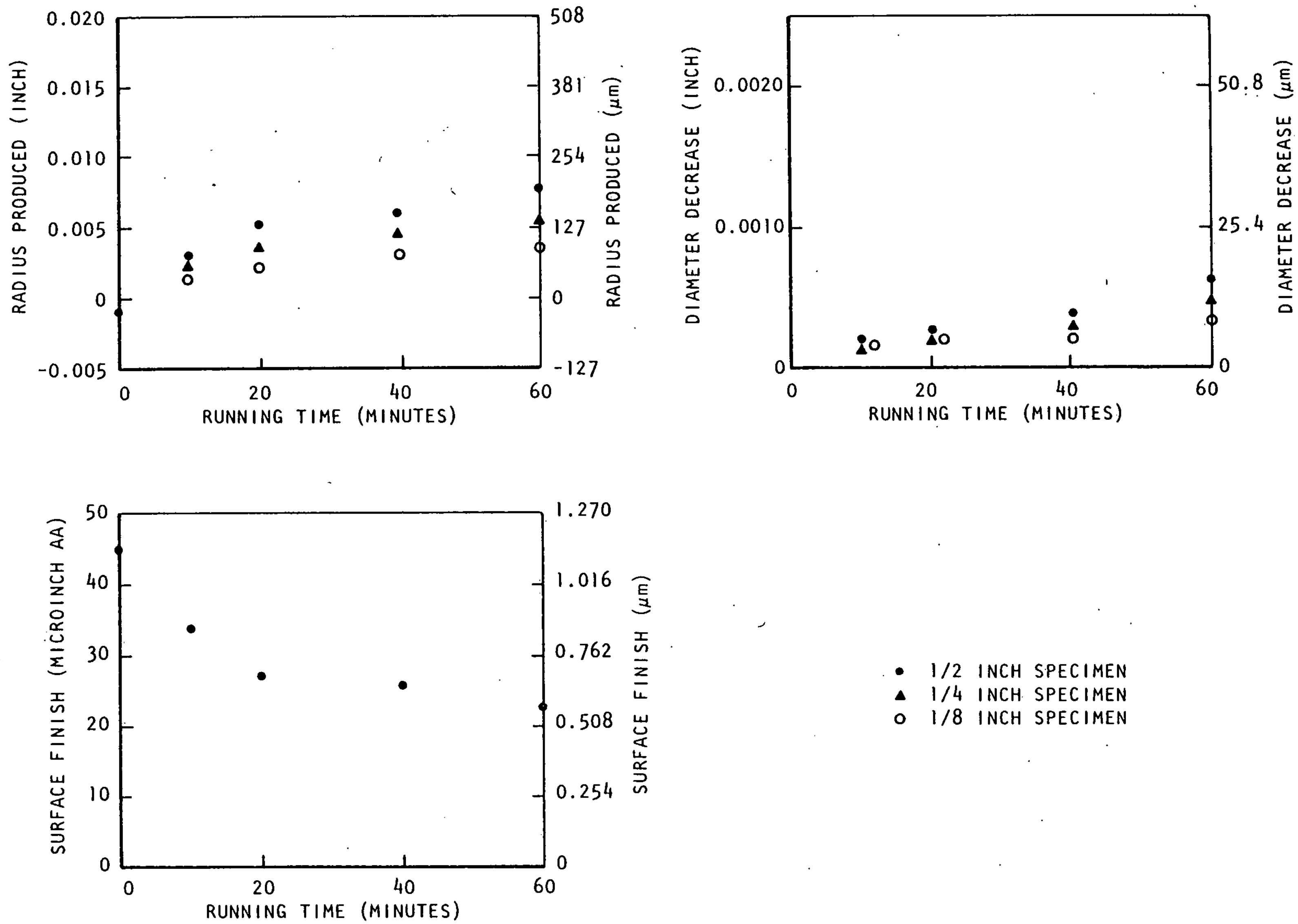


Figure 5. Harperizing Effects on Stainless Steel Cylinders, Using N14 Nuggets and 1A-1 Compound at 15 g's

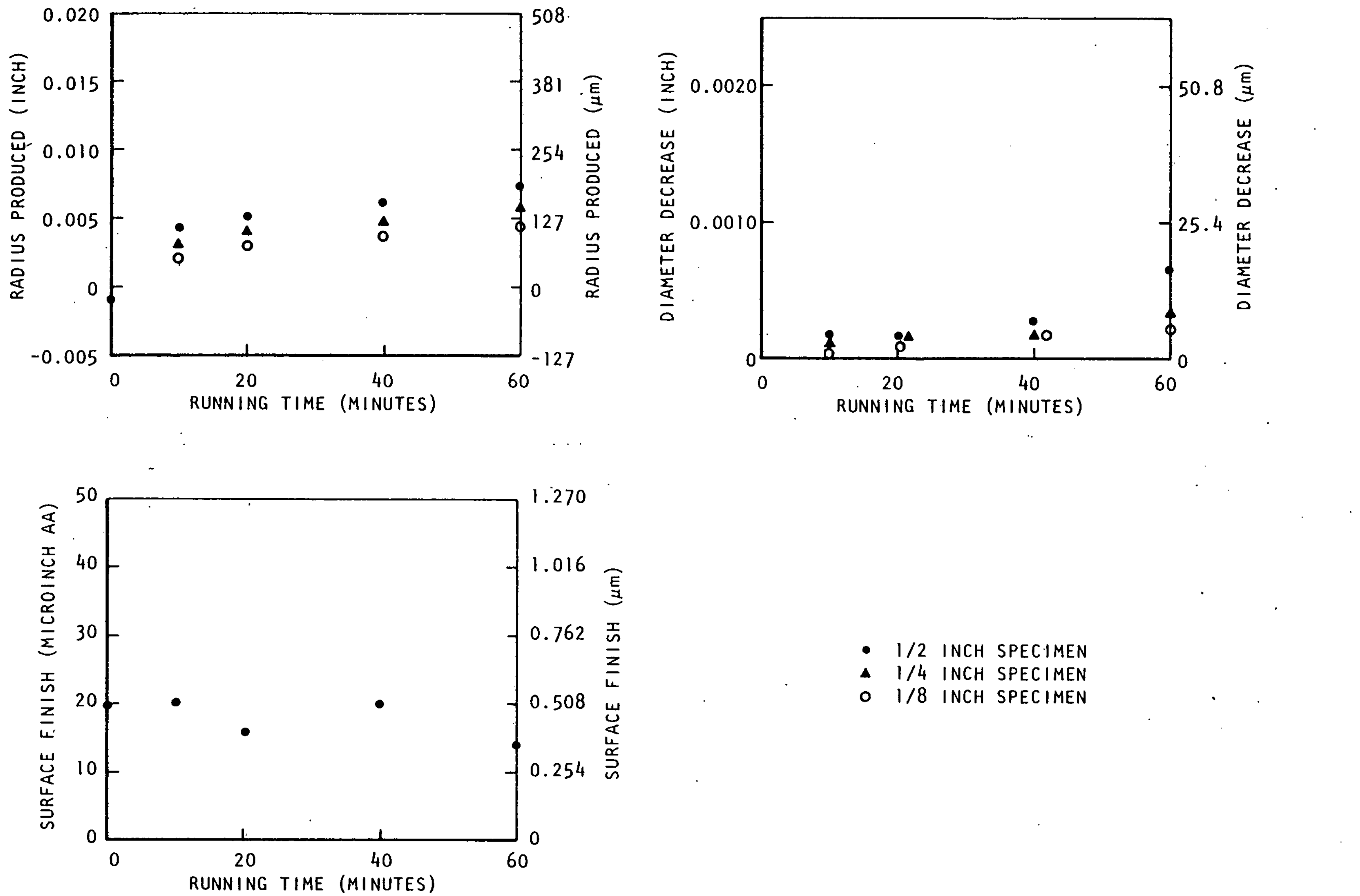


Figure 6. Harperizing Effects on Aluminum Cylinders, Using N14 Nuggets and 1A-1 Compound at 15 g's

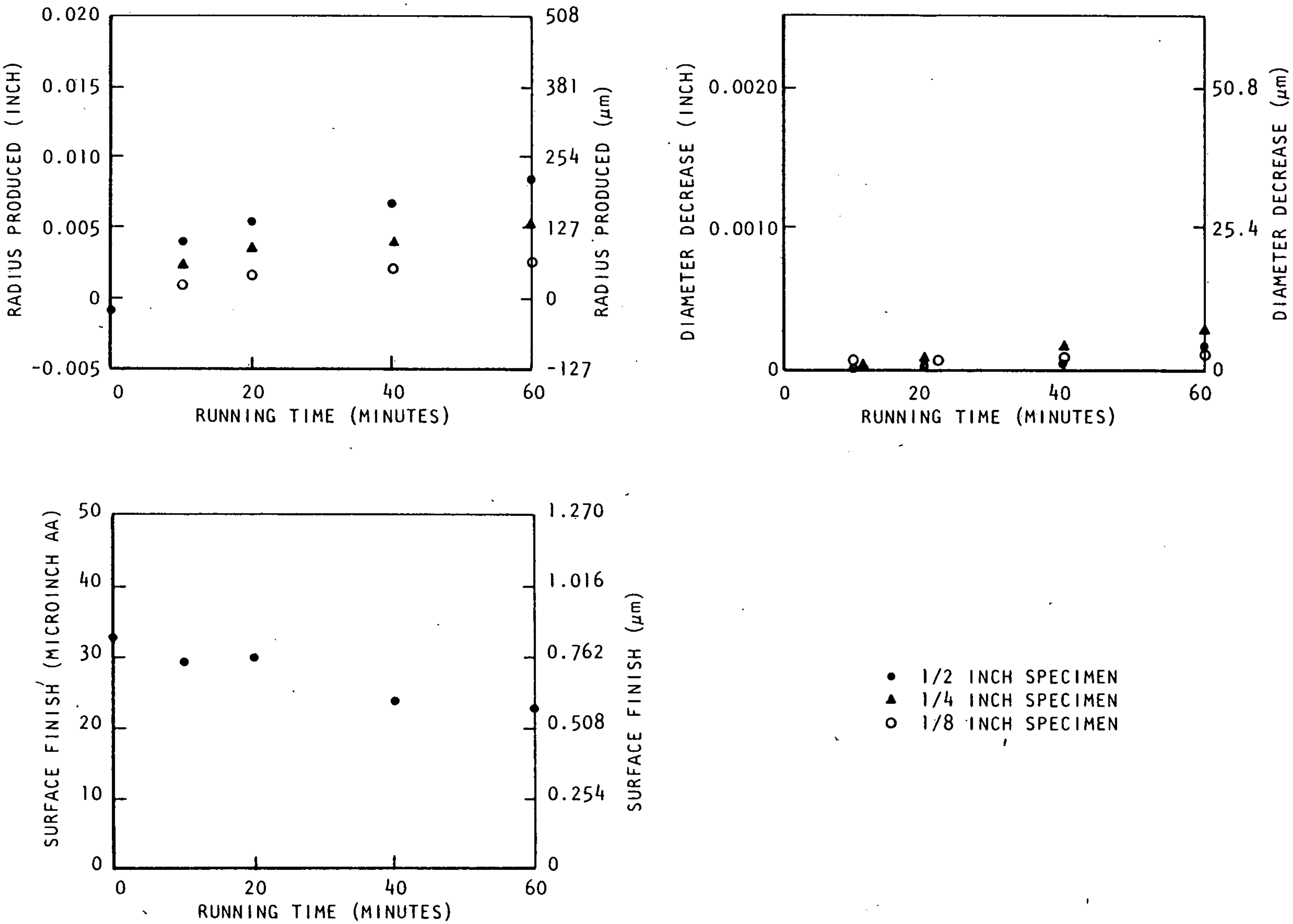


Figure 7. Harperizing Effects on 1018 Steel Cylinders, Using N12 Dolamite and No Compound at 15 g's

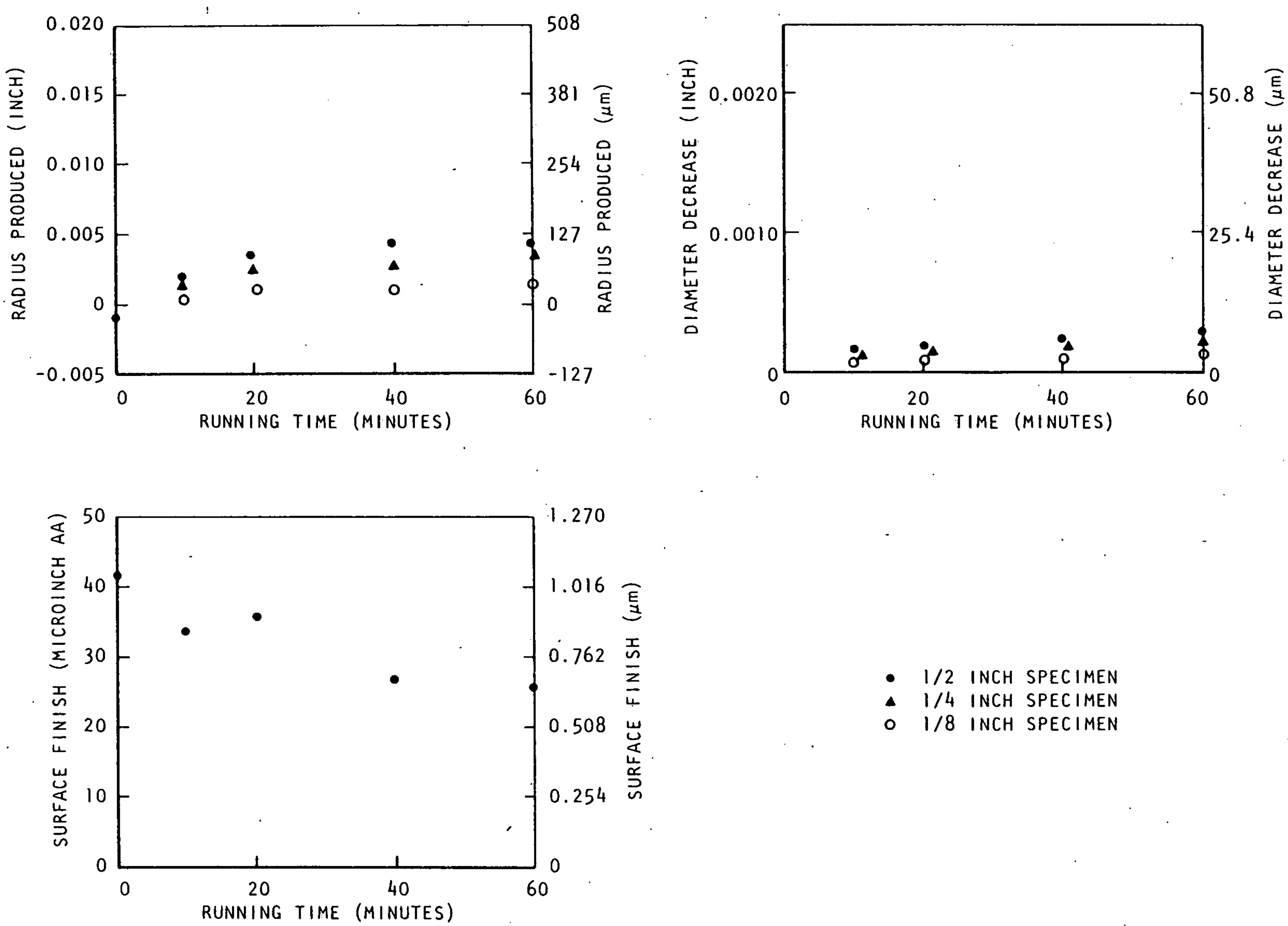


Figure 8. Harperizing Effects on Stainless Steel Cylinders, Using N12 Dolamite and No Compound at 15 g's

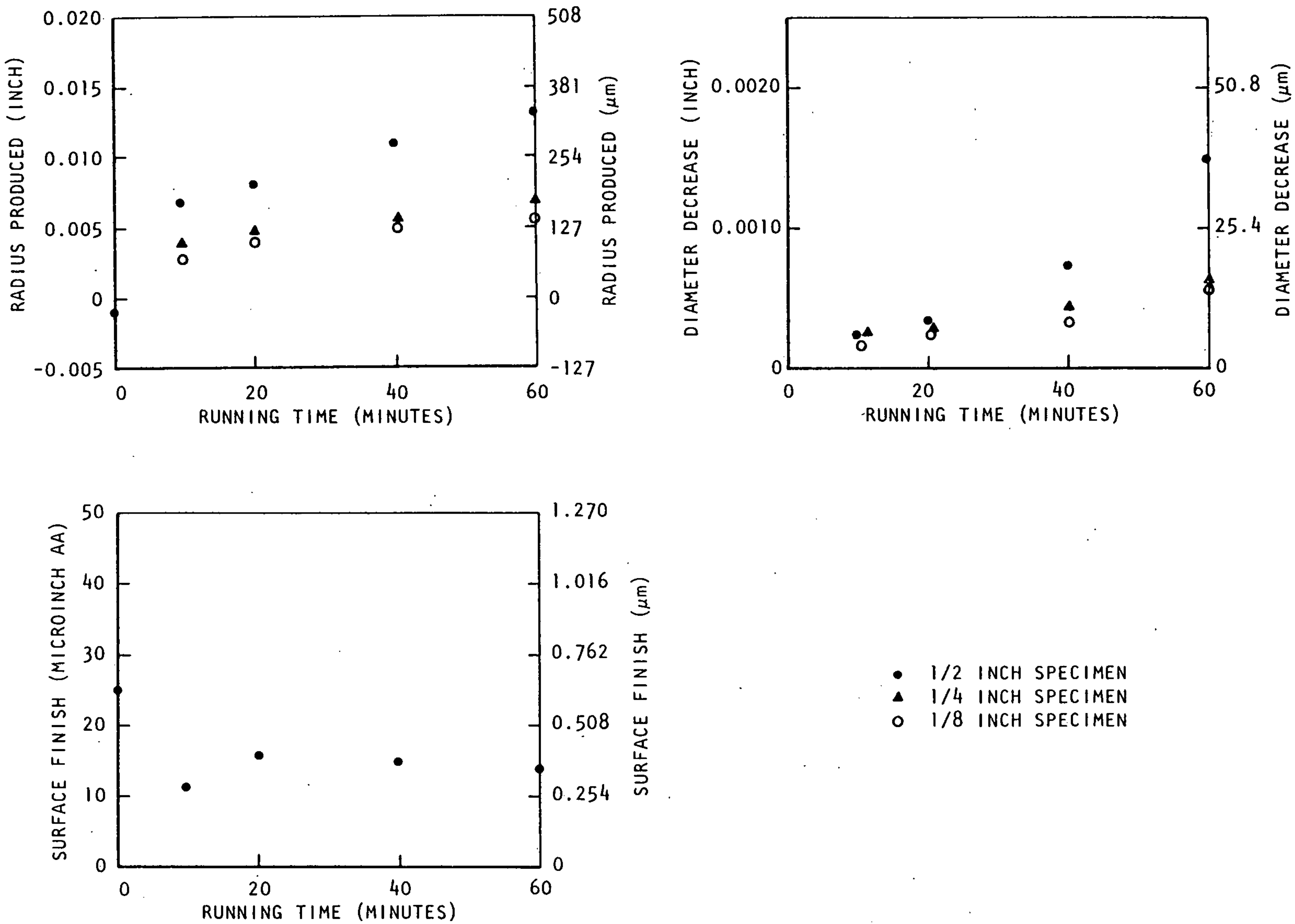


Figure 9. Harperizing Effects on Aluminum Cylinders, Using N12 Dolamite and No Compound at 15 g's

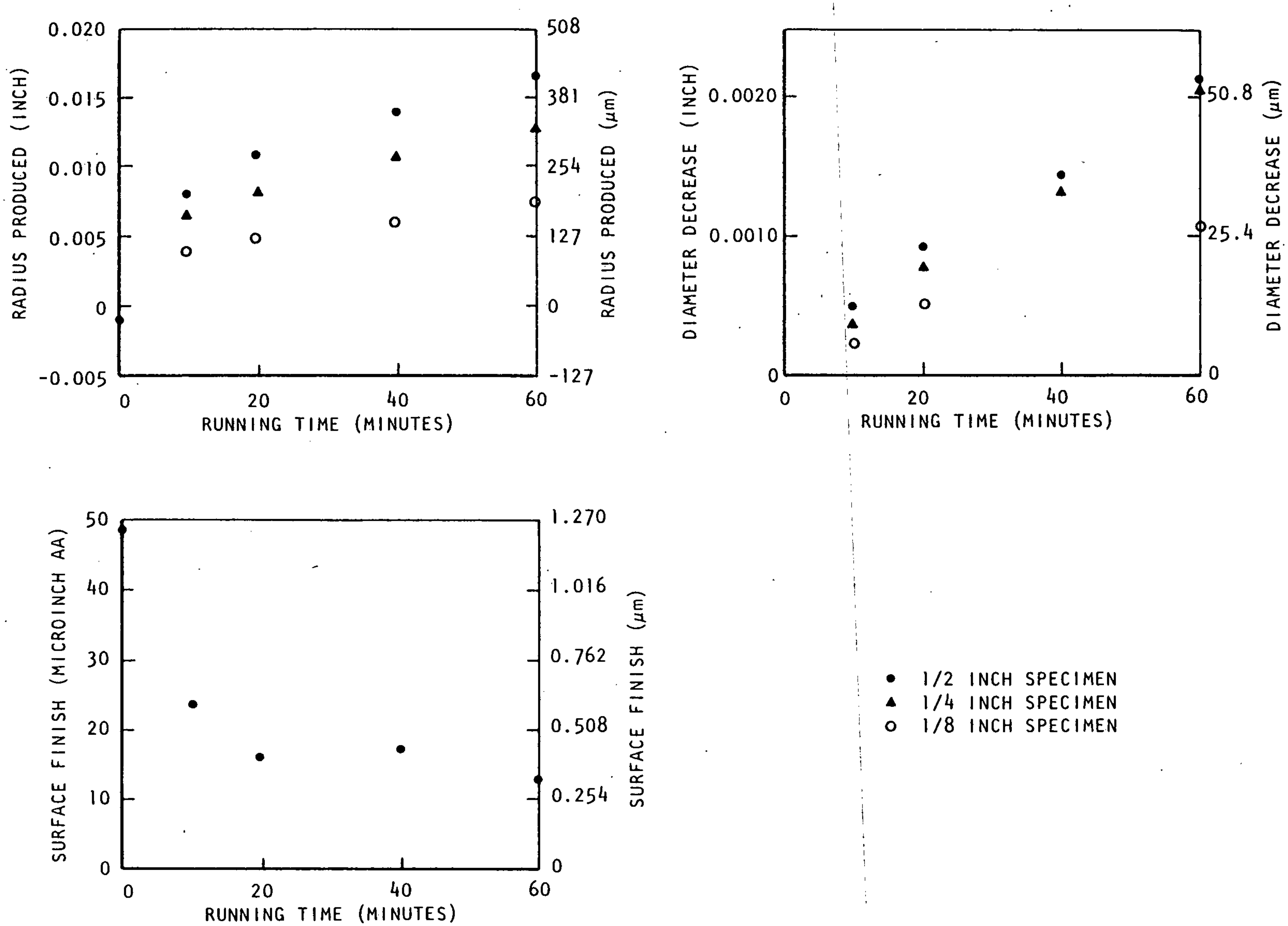


Figure 10. Harperizing Effects on 1018 Steel Cylinders, Using 3/16 Triangles and 1A-1 Compound at 15 g's

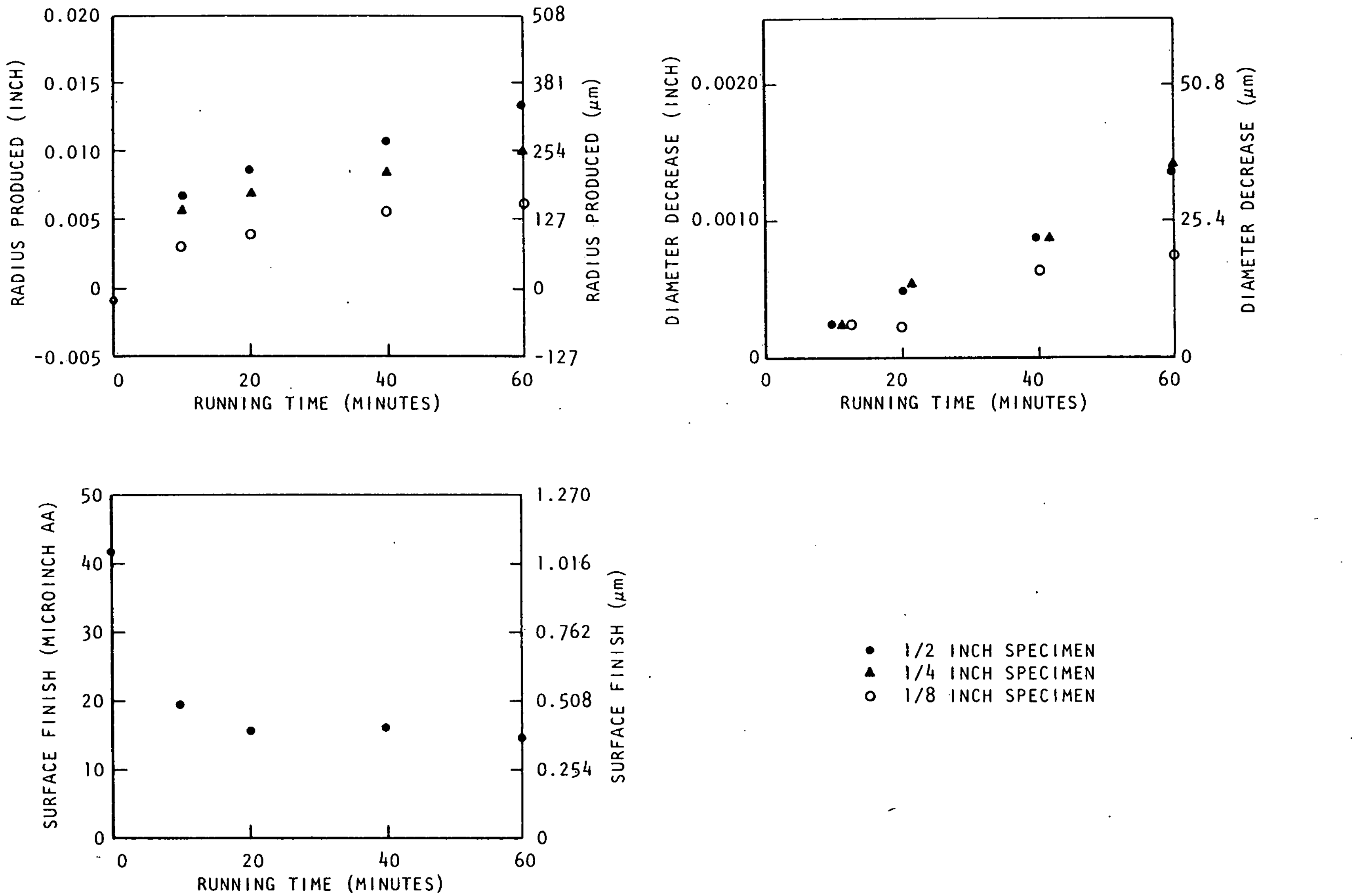


Figure 11. Harperizing Effects on Stainless Steel Cylinders, Using 3/16 Triangles and 1A-1 Compound at 15 g's

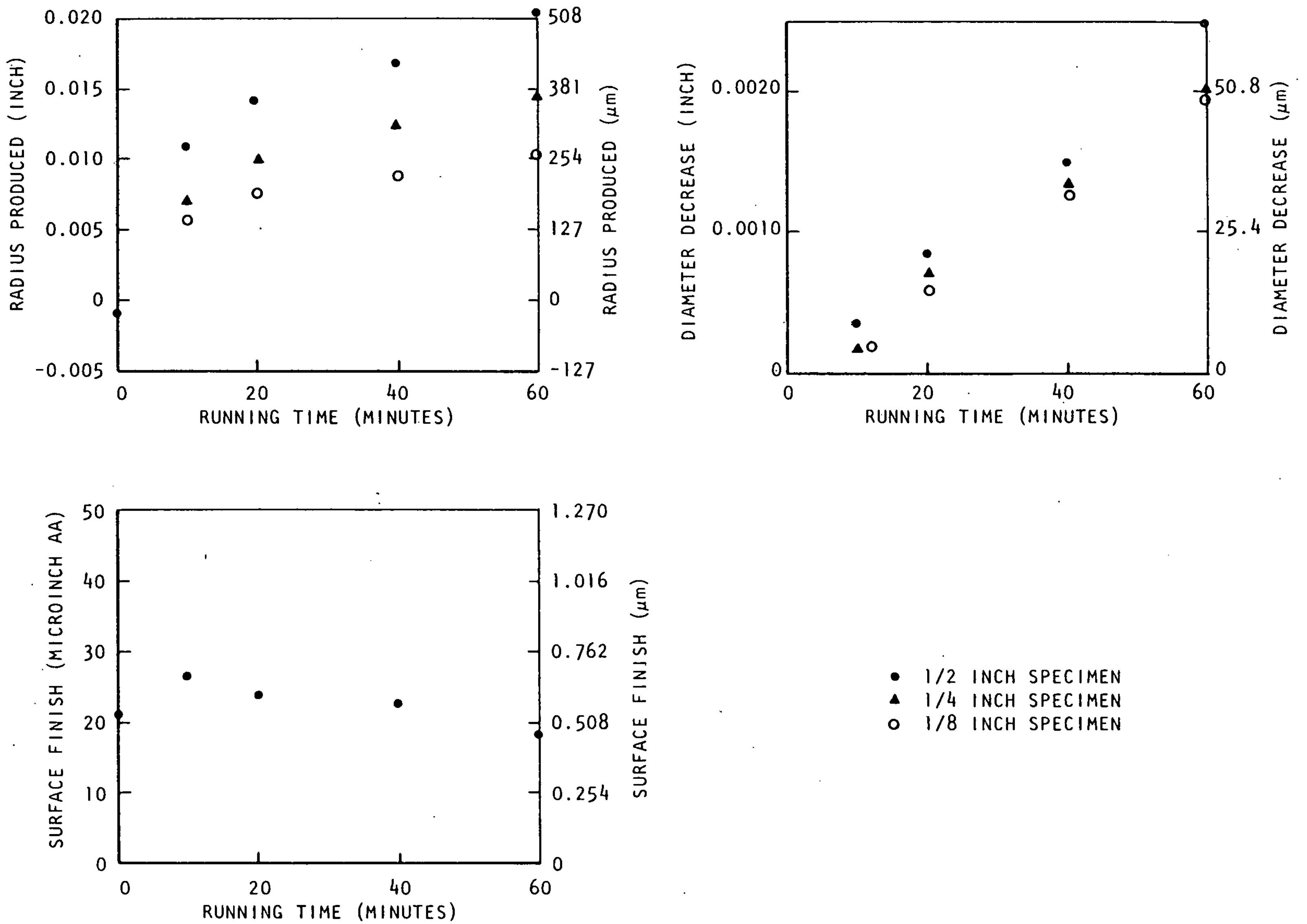


Figure 12. Harperizing Effects on Aluminum Cylinders, Using 3/16 Triangles and 1A-1 Compound at 15 g's

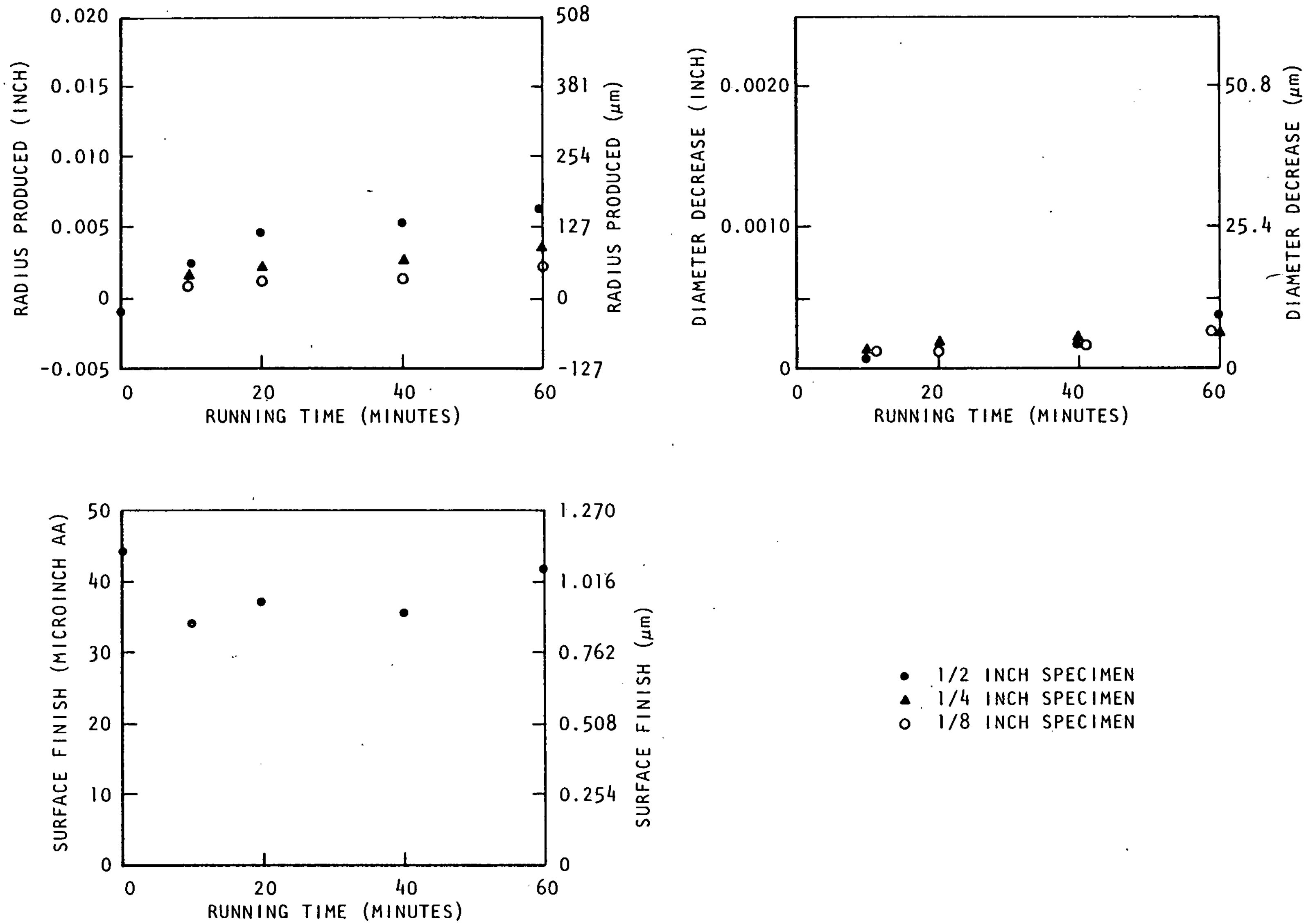


Figure 13. Harperizing Effects on 1018 Steel Cylinders, Using N24 Nuggets and 1A-1 Compound at 15 g's

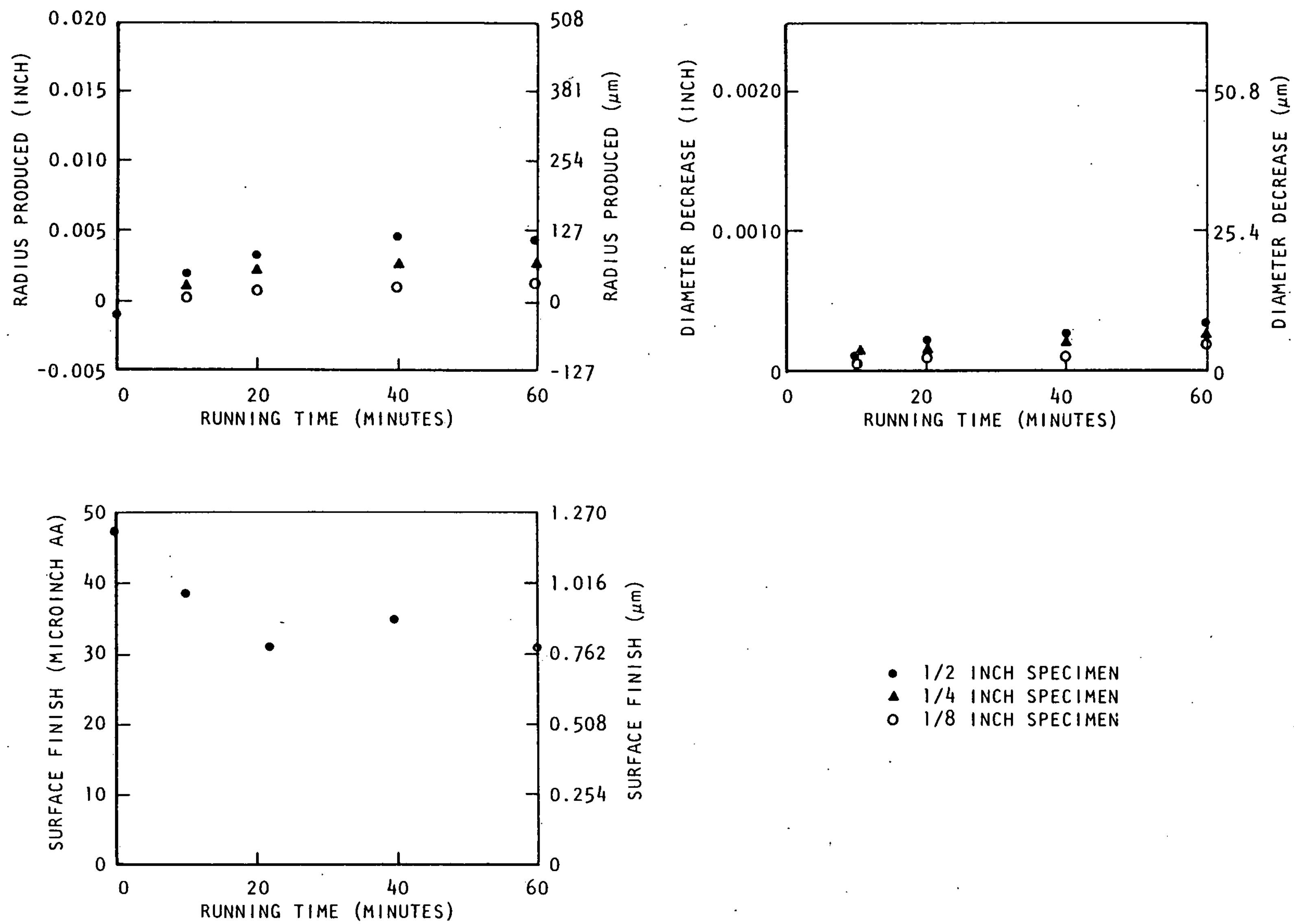


Figure 14. Harperizing Effects on Stainless Steel Cylinders, Using N24 Nuggets and 1A-1 Compound at 15 g's

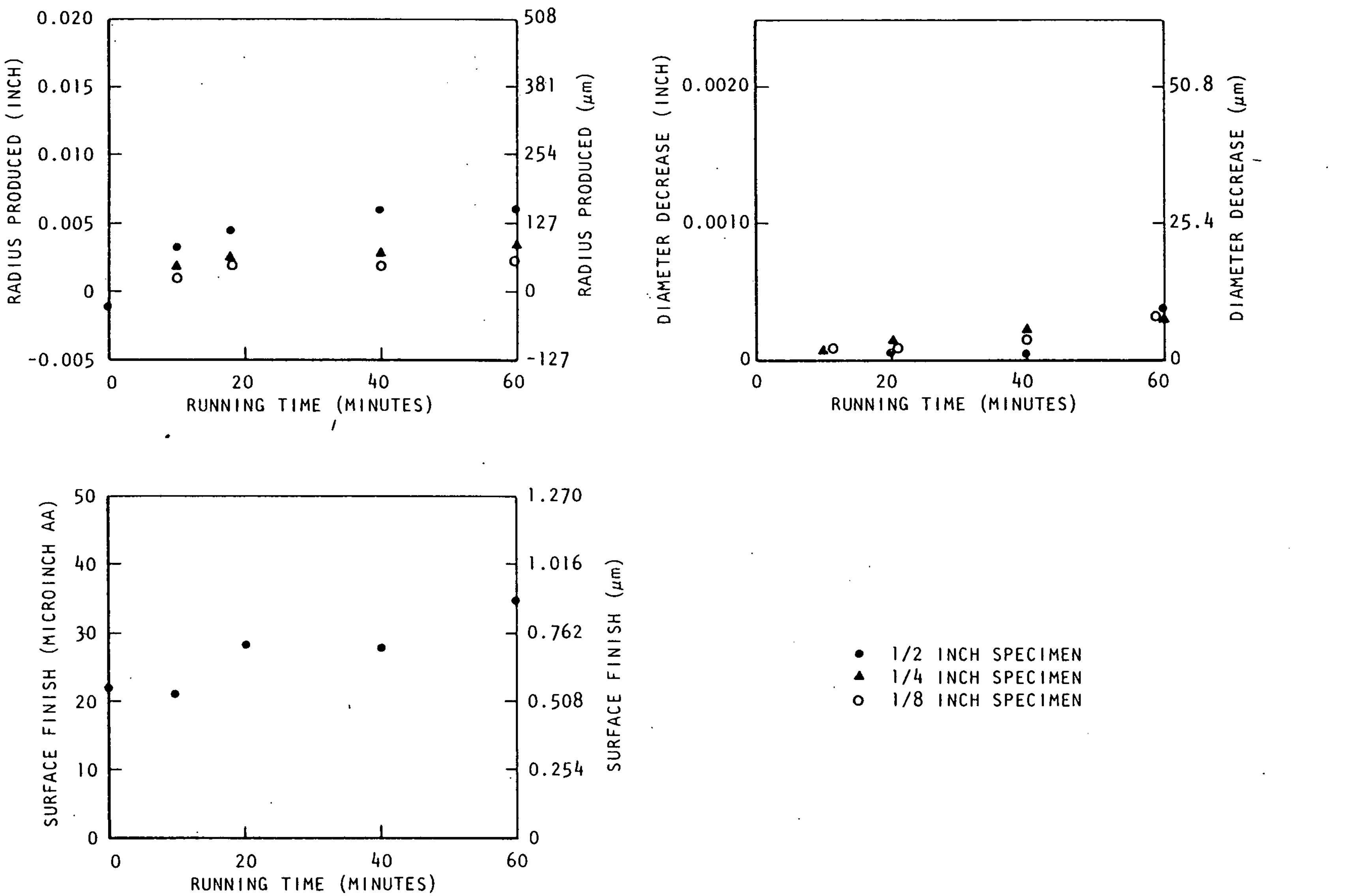


Figure 15. Harperizing Effects on Aluminum Cylinders, Using N24 Nuggets and 1A-1 Compound at 15 g's

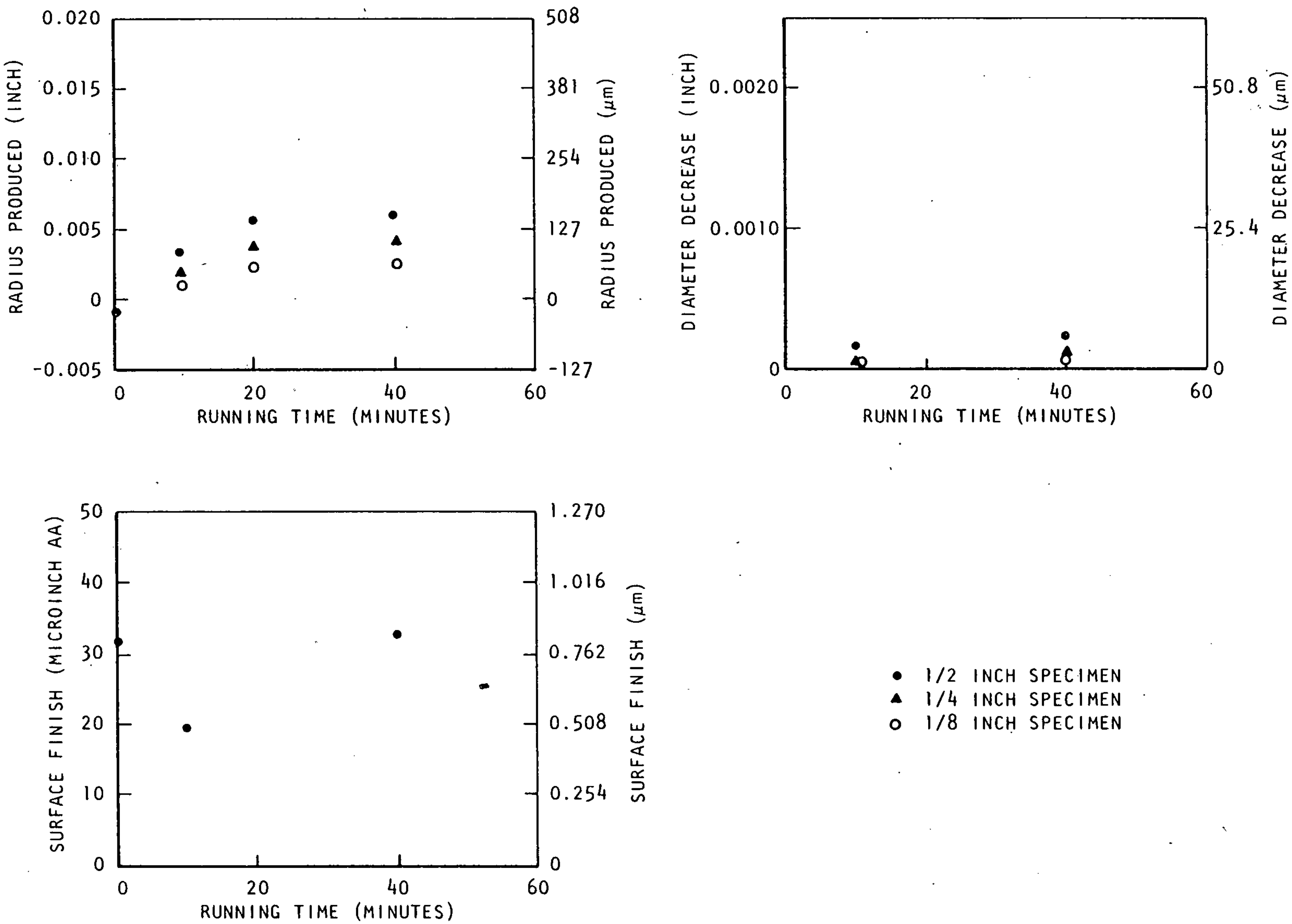


Figure 16. Harperizing Effects on 1018 Steel Cylinders, Using N14 Nuggets and 1A-1 Compound at 20 g's

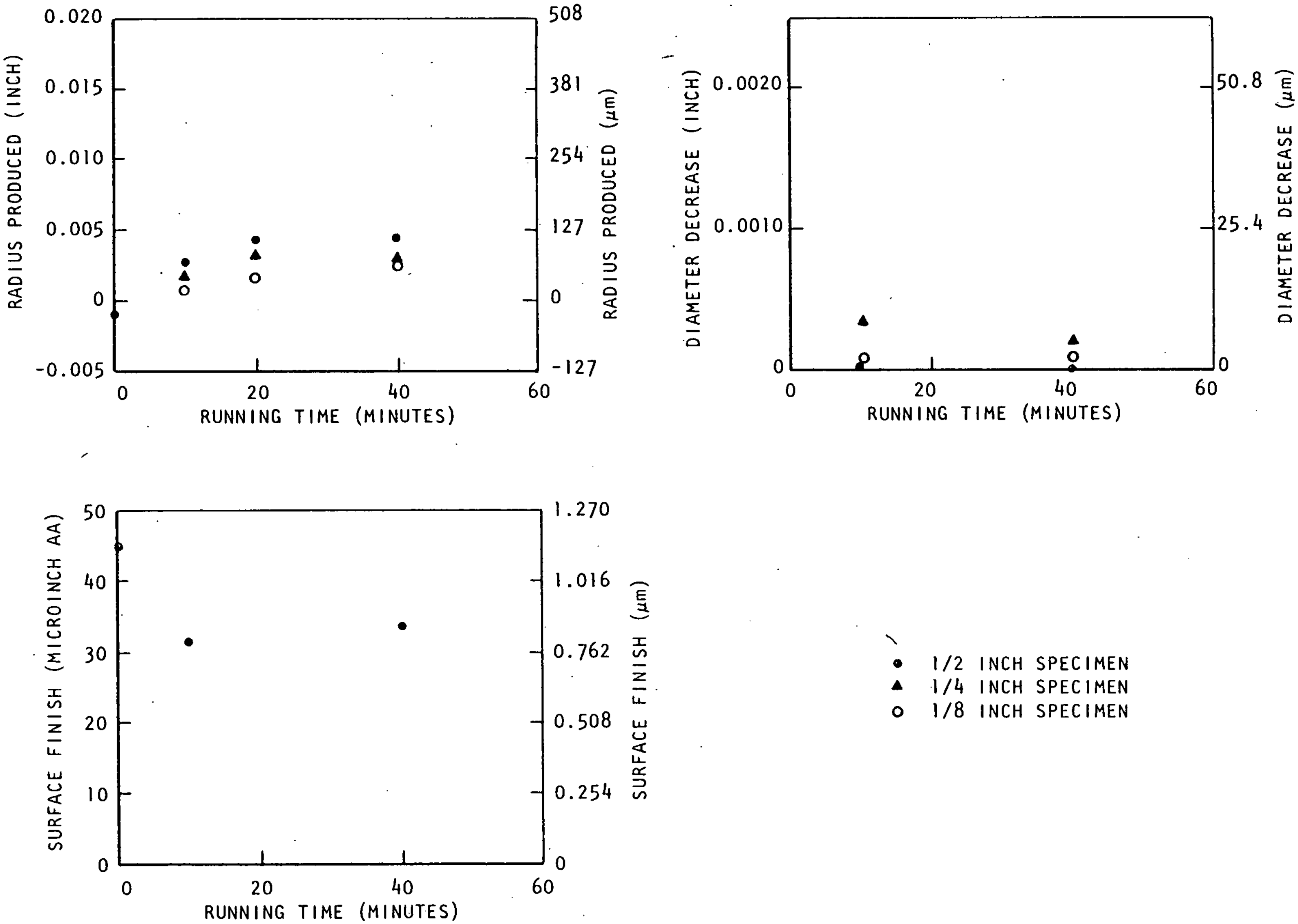


Figure 17. Harperizing Effects on Stainless Steel Cylinders, Using N14 Nuggets and 1A-1 Compound at 20 g's

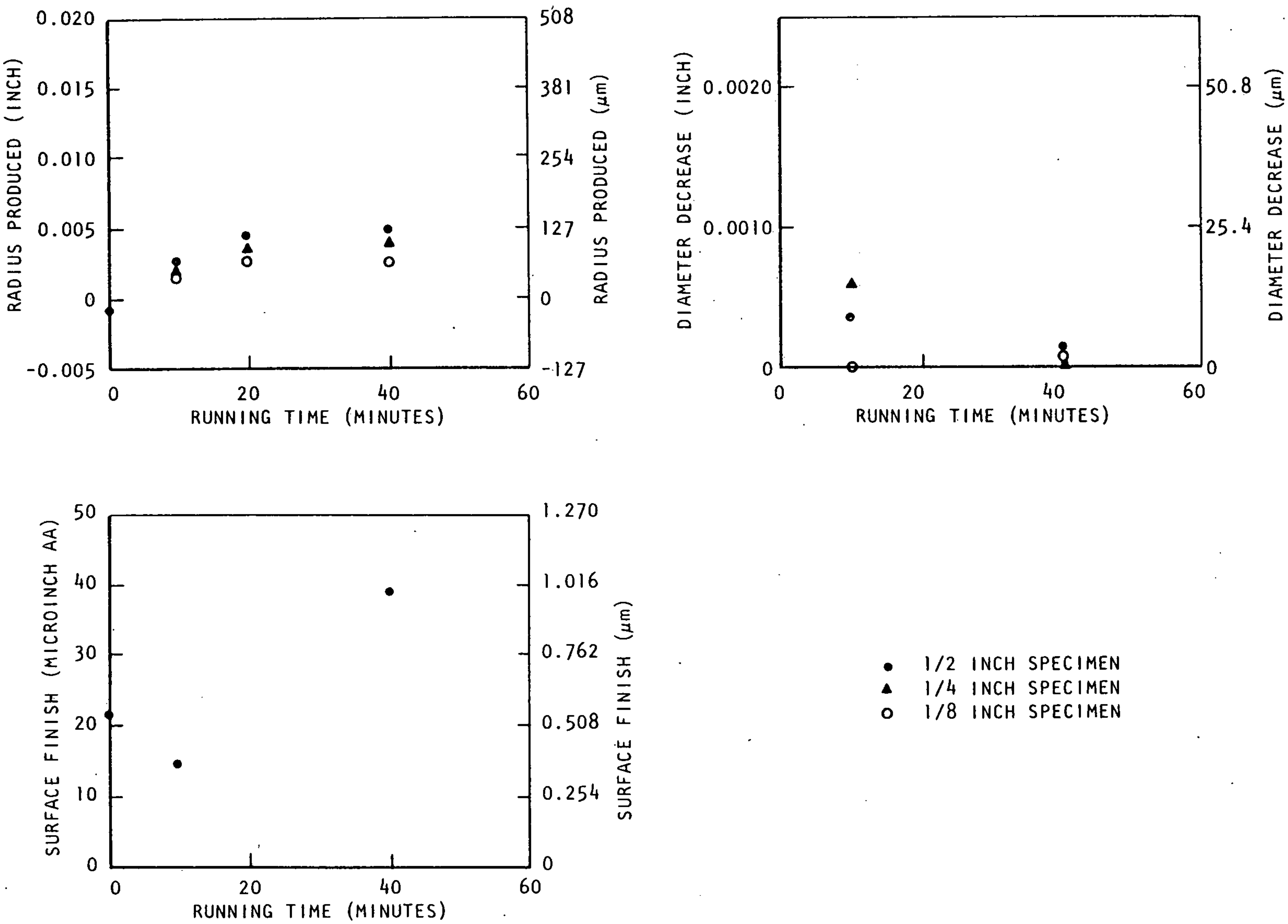


Figure 18. Harperizing Effects on Aluminum Cylinders, Using N14 Nuggets and 1A-1 Compound at 20 g's

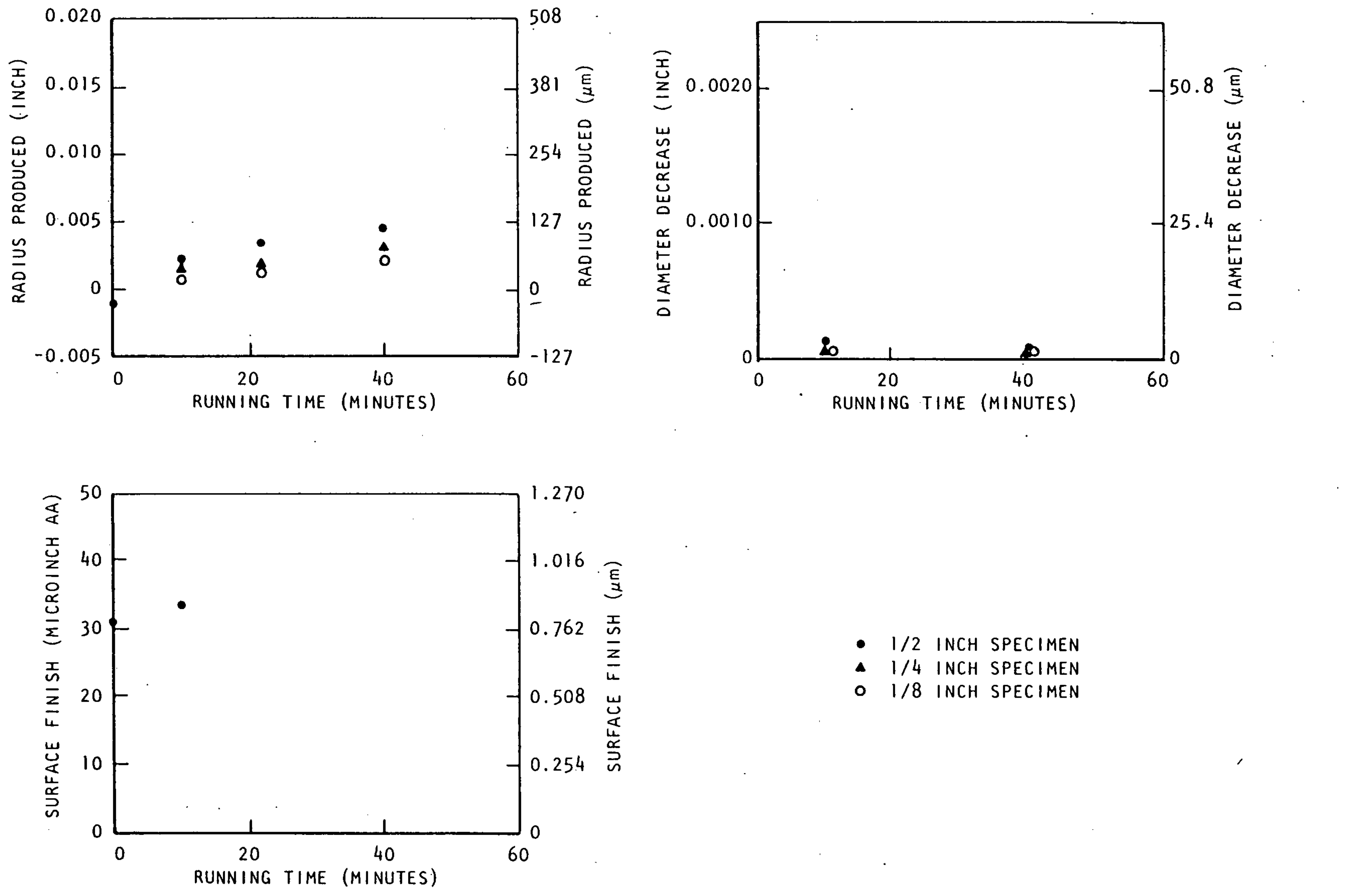


Figure 19. Harperizing Effects on 1018 Steel Cylinders, Using N14 Nuggets and 1A-1 Compound at 5 g's

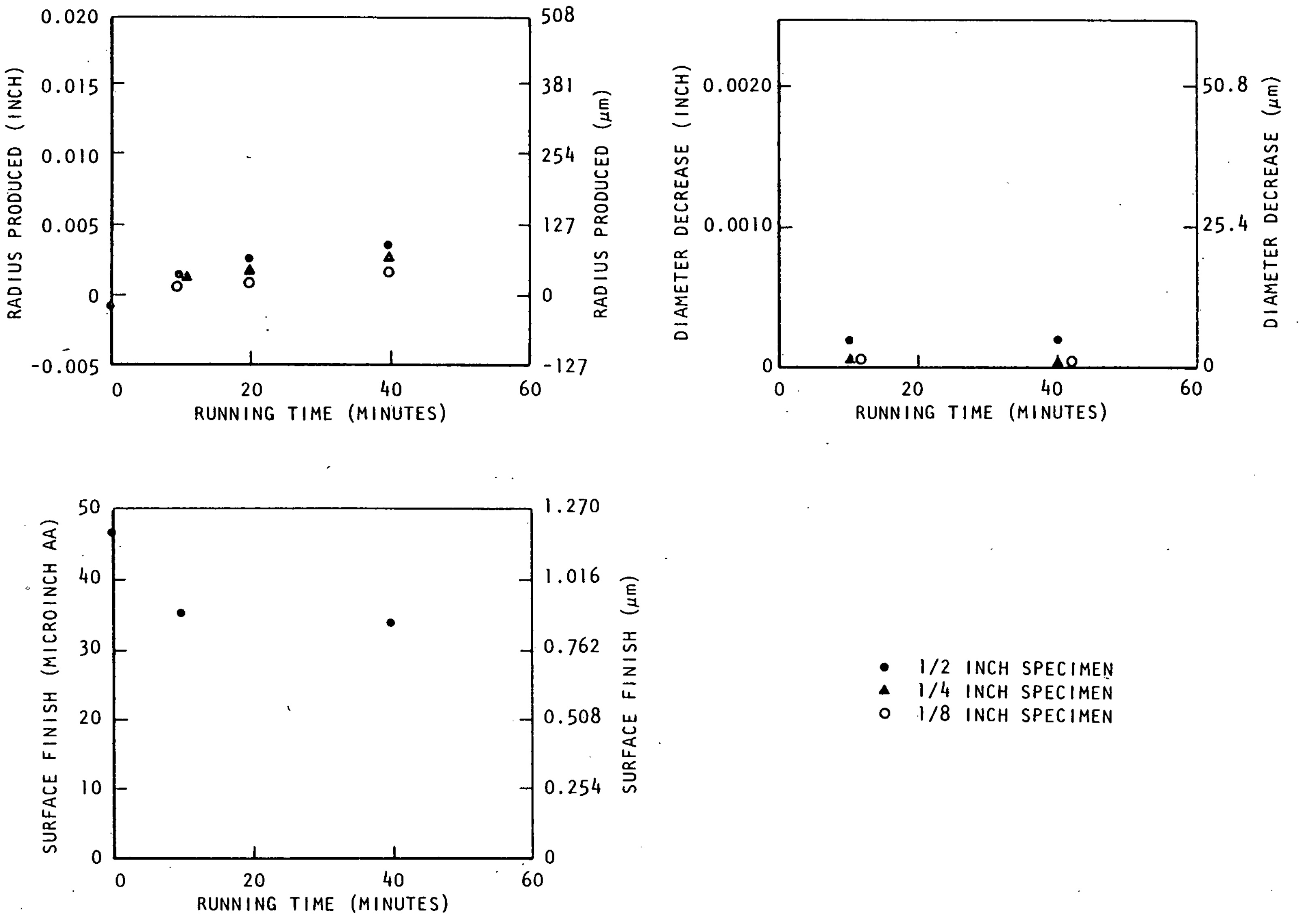


Figure 20. Harperizing Effects on Stainless Steel Cylinders, Using N14 Nuggets and 1A-1 Compound at 5 g's

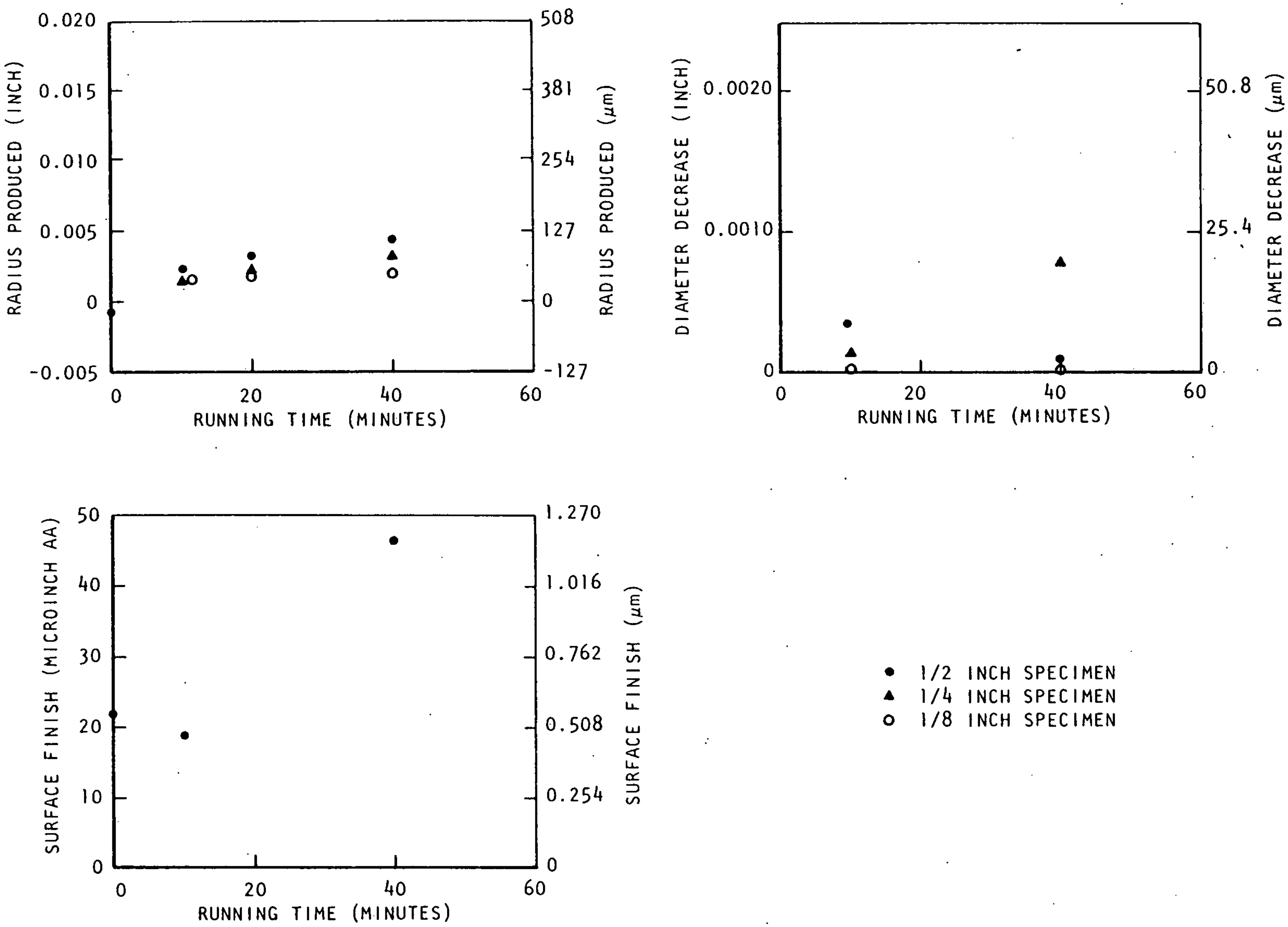


Figure 21. Harperizing Effects on Aluminum Cylinders, Using N14 Nuggets and 1A-1 Compound at 5 g's

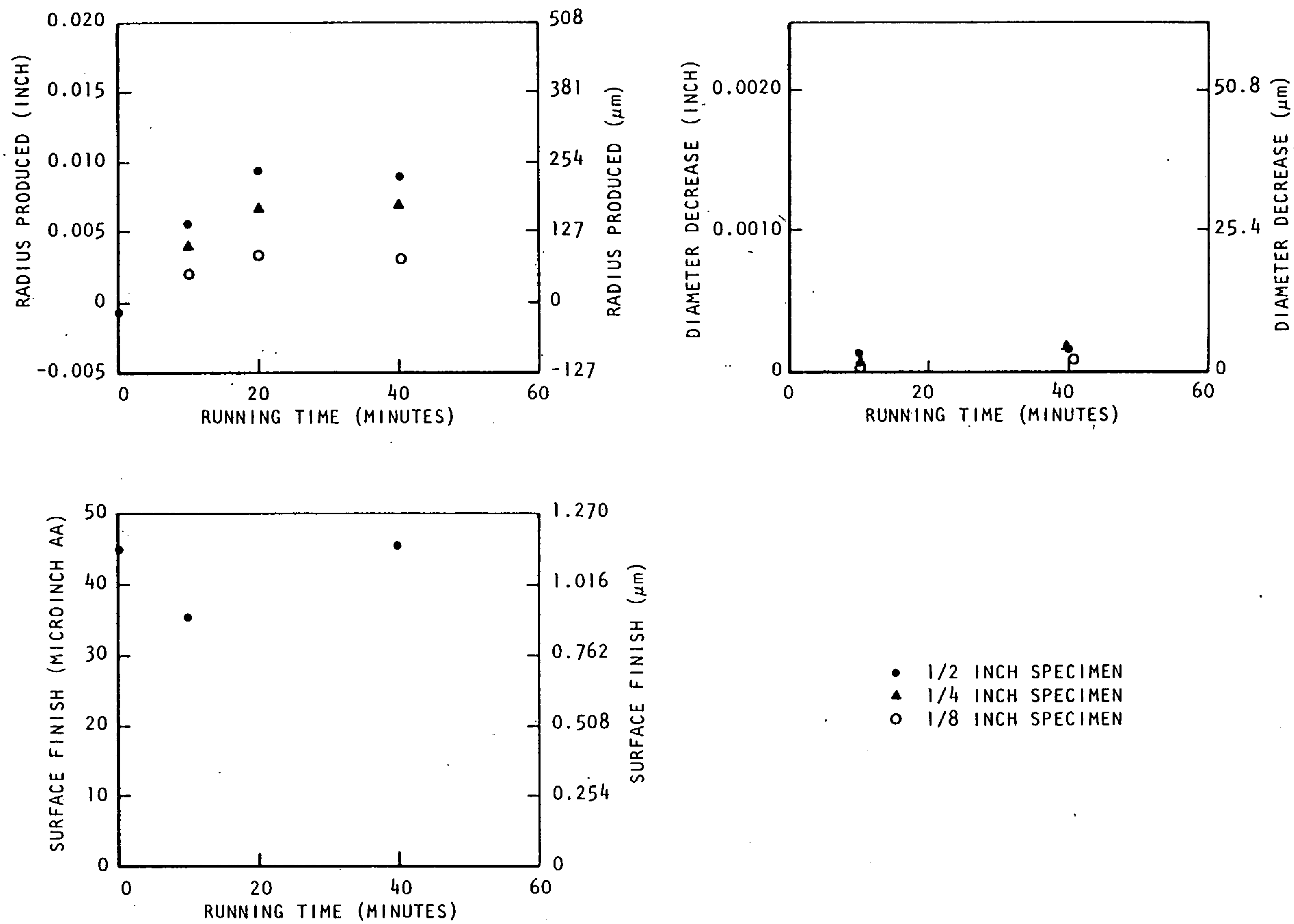


Figure 22. Harperizing Effects on 1018 Steel Cylinders, Using 1/4-Inch Plastic Pyramids and 1A-1 Compound at 15 g's

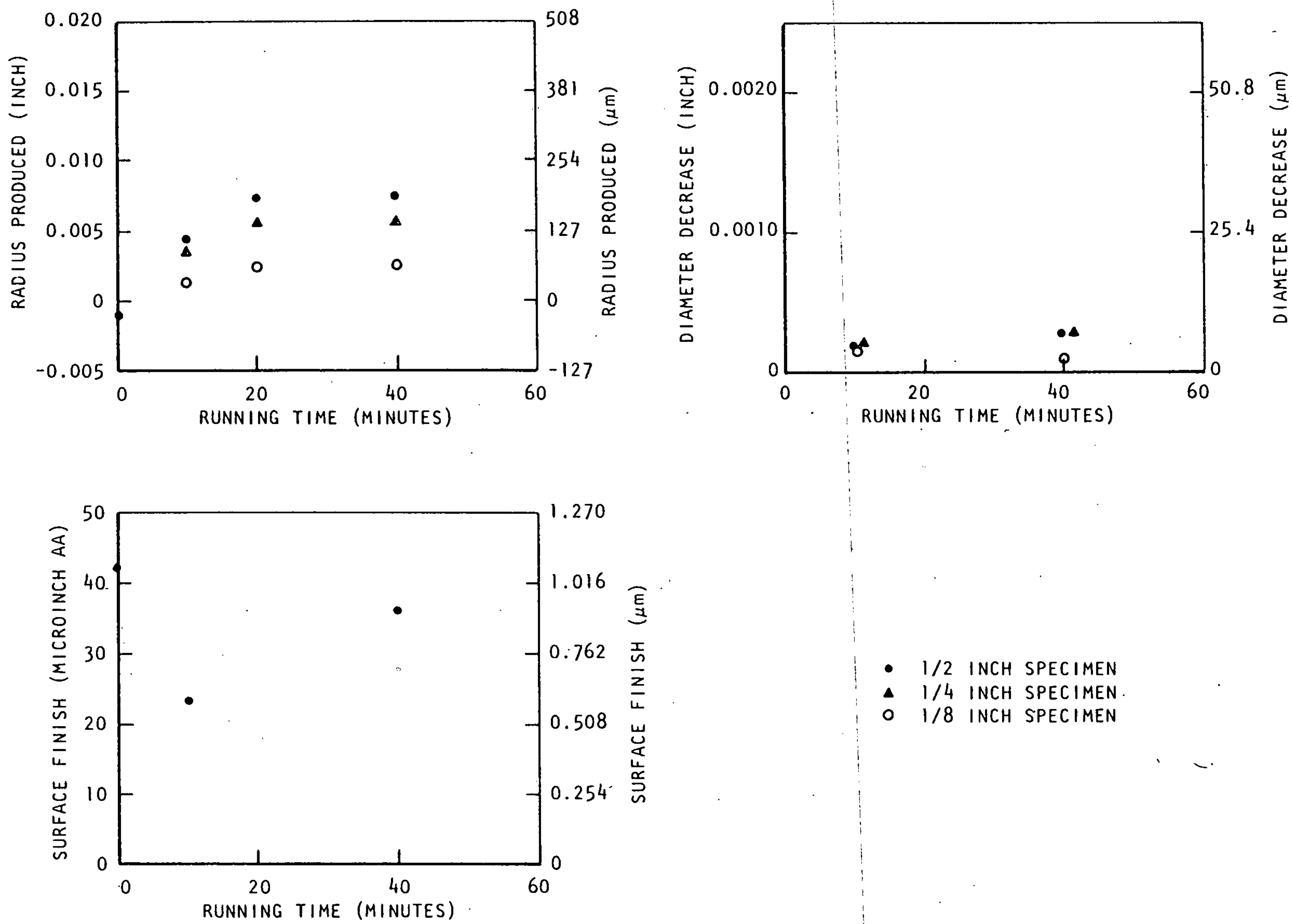


Figure 23. Harperizing Effects on Stainless Steel Cylinders, Using 1/4-Inch Plastic Pyramids and 1A-1 Compound at 15 g's

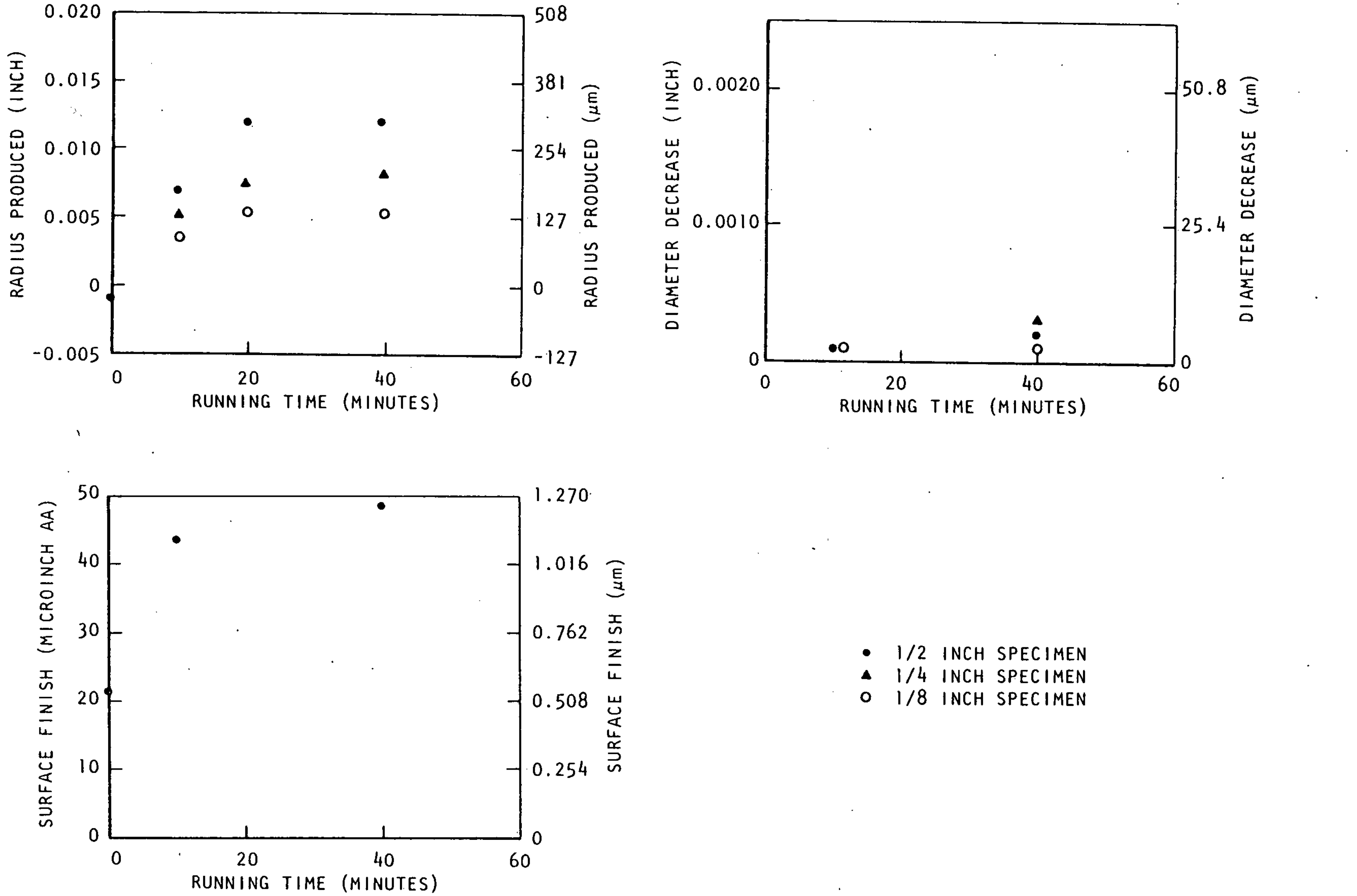


Figure 24. Harperizing Effects on Aluminum Cylinders, Using 1/4-Inch Plastic Pyramids and 1A-1 Compound at 15 g's

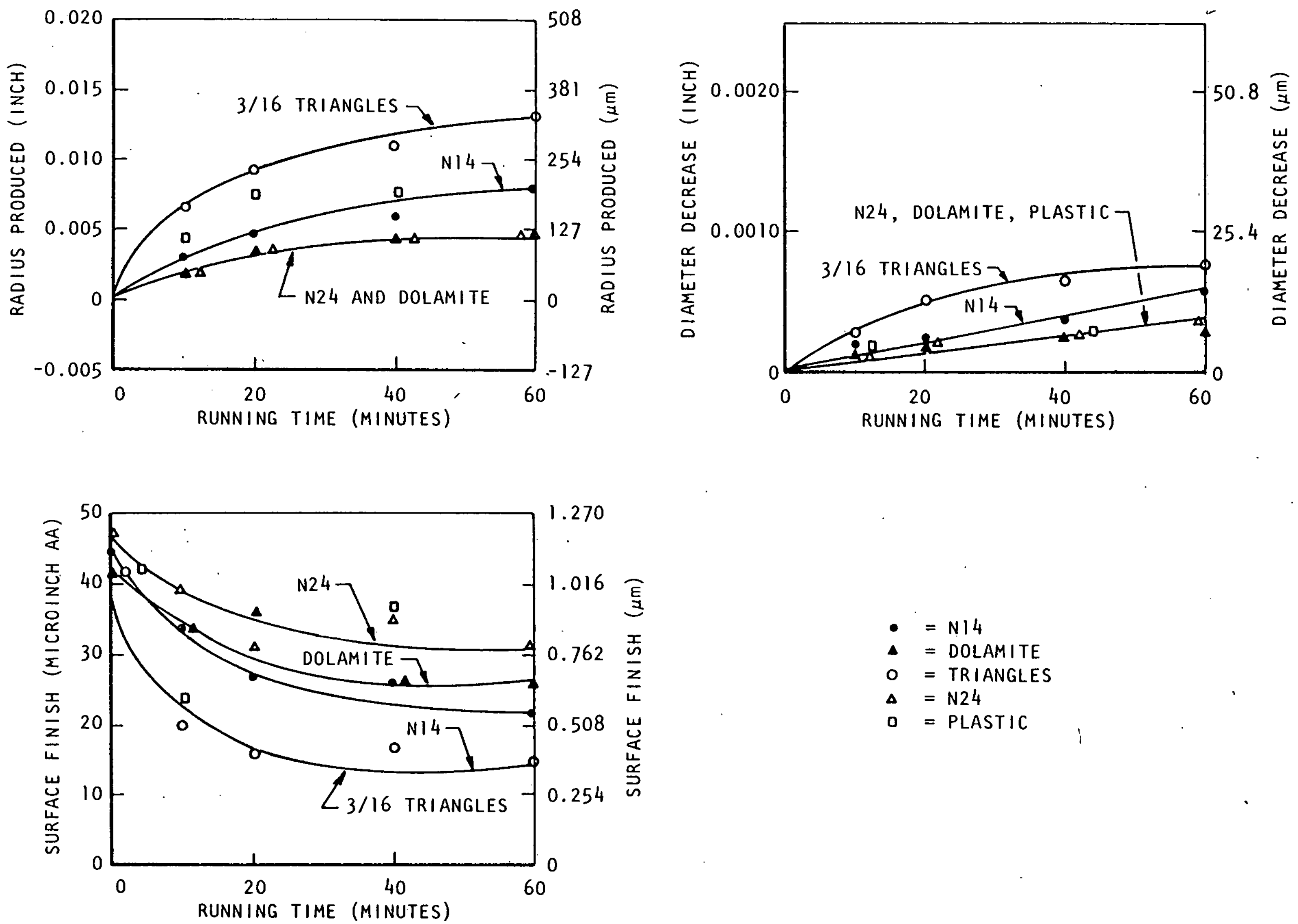


Figure 25. Harperizing Effects on 0.5-Inch (12.7 mm) Stainless Steel Cylinders, Using Various Media and 1A-1 Compound at 15 g's

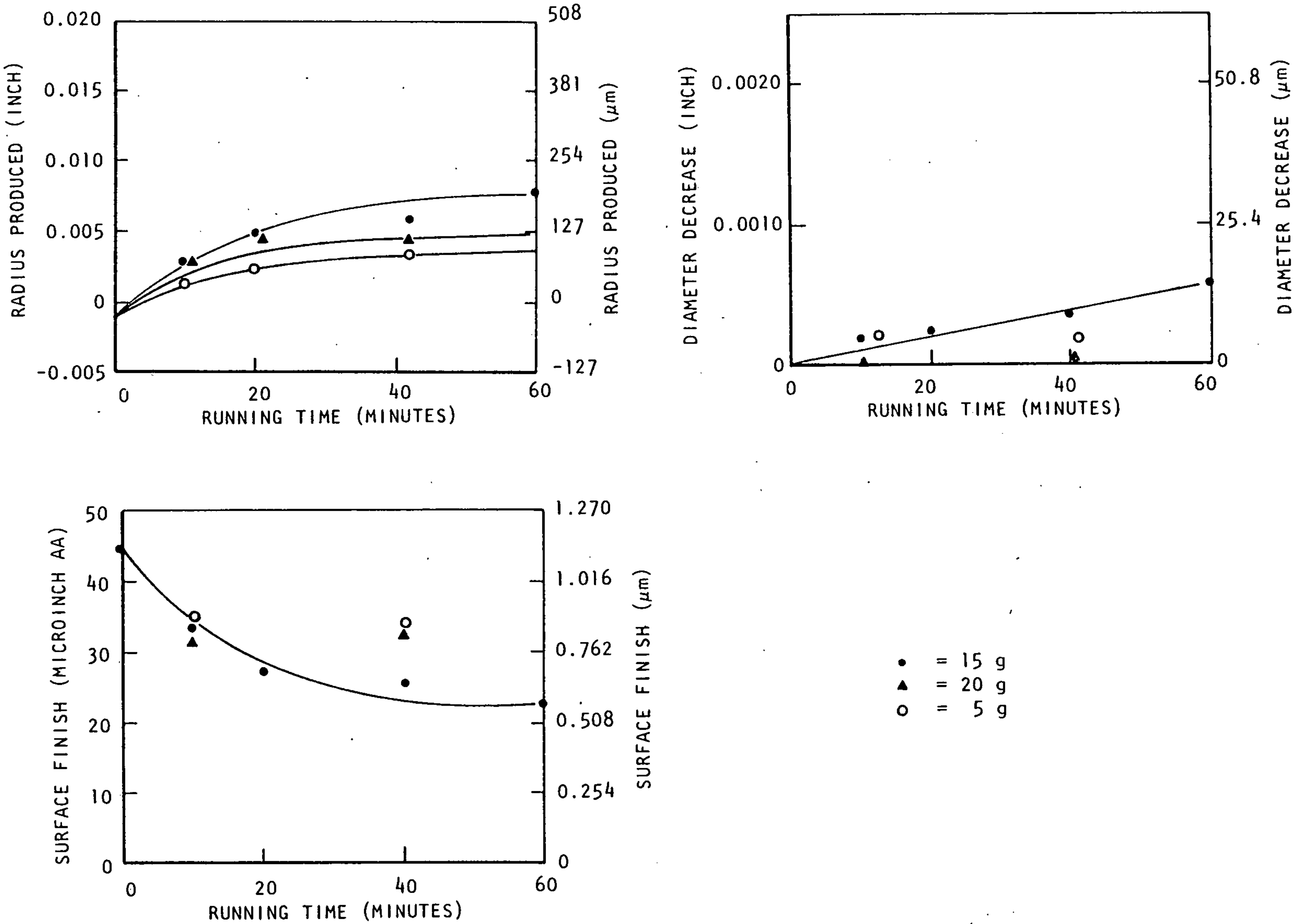


Figure 26. Harperizing Effects on 0.5-Inch (12.7 mm) Stainless Steel Cylinders, Using N14 Nuggets and 1A-1 Compound at Various g Levels

Table 3. Equations for Edge Radiusing, 303 Se Stainless Steel

	Part Diameter (Inch)*		
Conditions	0.5	0.25	0.115
(I) Al_2O_3 N14 at 15g	$R = 0.00113t^{0.46}$ $\sigma_R = 0.00025$	$R = 0.00095t^{0.42}$ $\sigma_R = 0.00016$	$R = 0.00063t^{0.43}$ $\sigma_R = 0.00014$
(II) Dolamite at 15g	$R = 0.00072t^{0.48}$ $\sigma_R = 0.00031$	$R = 0.00055t^{0.46}$ $\sigma_R = 0.00017$	$R = 0.00032t^{0.35}$ $\sigma_R = 0.00012$
(III) 3/16-Inch Ceramic Triangles at 15g	$R = 0.00281t^{0.37}$ $\sigma_R = 0.00029$	$R = 0.00241t^{0.35}$ $\sigma_R = 0.00011$	$R = 0.00131t^{0.38}$ $\sigma_R = 0.00023$
(IV) Al_2O_3 N24 at 15g	$R = 0.00071t^{0.48}$ $\sigma_R = 0.00034$	$R = 0.00036t^{0.53}$ $\sigma_R = 0.00034$	$R = 0.00012t^{0.61}$ $\sigma_R = 0.00011$
(V) Al_2O_3 N14 at 20g	$R = 0.00106t^{0.43}$ $\sigma_R = 0.00033$	$R = 0.00032t^{0.68}$ $\sigma_R = 0.00045$	$R = 0.00010t^{0.93}$ $\sigma_R = 0.00022$
(VI) Al_2O_3 N14 at 5g	$R = 0.00037t^{0.62}$ $\sigma_R = 0.00012$	$R = 0.00037t^{0.51}$ $\sigma_R = 0.00025$	$R = 0.00017t^{0.62}$ $\sigma_R = 0.00006$
(VII) 1/4-Inch Plastic Pyramids at 15 g	$R = 0.00246t^{0.31}$ $\sigma_R = 0.00053$	$R = 0.00179t^{0.34}$ $\sigma_R = 0.00036$	$R = 0.00060t^{0.40}$ $\sigma_R = 0.00020$

*0.001 inch = 25.4 μm. Radius (R) is in inches, where t = time in minutes. Standard deviation (σ_R) is in inches.

Table 4. Equations for Edge Radiusing, 1018 Steel

Conditions	Part Diameter (Inch)* 0.5	0.25	0.115
(I) Al_2O_3 N14 at 15g	$R = 0.00148t^{0.44}$ $\sigma_R = 0.00032$	$R = 0.00126t^{0.38}$ $\sigma_R = 0.00035$	$R = 0.00076t^{0.41}$ $\sigma_R = 0.00018$
(II) Dolamite at 15g	$R = 0.00171t^{0.38}$ $\sigma_R = 0.00019$	$R = 0.00098t^{0.40}$ $\sigma_R = 0.00019$	$R = 0.00043t^{0.46}$ $\sigma_R = 0.00009$
(III) 3/16-Inch Ceramic Triangles at 15g	$R = 0.00343t^{0.38}$ $\sigma_R = 0.00013$	$R = 0.00251t^{0.40}$ $\sigma_R = 0.00016$	$R = 0.00168t^{0.35}$ $\sigma_R = 0.00014$
(IV) Al_2O_3 N24 at 15g	$R = 0.00103t^{0.45}$ $\sigma_R = 0.00039$	$R = 0.00043t^{0.52}$ $\sigma_R = 0.00012$	$R = 0.00021t^{0.57}$ $\sigma_R = 0.00005$
(V) Al_2O_3 N14 at 20g	$R = 0.00143t^{0.41}$ $\sigma_R = 0.00054$	$R = 0.00068t^{0.51}$ $\sigma_R = 0.00037$	$R = 0.00055t^{0.42}$ $\sigma_R = 0.00020$
(VI) Al_2O_3 N14 at 5g	$R = 0.00093t^{0.42}$ $\sigma_R = 0.00018$	$R = 0.00061t^{0.44}$ $\sigma_R = 0.00013$	$R = 0.00028t^{0.54}$ $\sigma_R = 0.00004$
(VII) 1/4-Inch Plastic Pyramids at 15g	$R = 0.00281t^{0.33}$ $\sigma_R = 0.00081$	$R = 0.00192t^{0.36}$ $\sigma_R = 0.00059$	$R = 0.00106t^{0.32}$ $\sigma_R = 0.00034$

*0.001 inch = 25.4 μm. Radius (R) is in inches, where t = time in minutes. Standard deviation (σ_R) is in inches.

Table 5. Equations for Edge Radiusing, 6061-T6 Aluminum

	Part Diameter (Inch)*		
Conditions	0.5	0.25	0.115
(I) Al_2O_3 N14 at 15g	$R = 0.00221t^{0.28}$ $\sigma_R = 0.00018$	$R = 0.00161t^{0.30}$ $\sigma_R = 0.00012$	$R = 0.00108t^{0.34}$ $\sigma_R = 0.00002$
(II) Dolamite at 15g	$R = 0.00299t^{0.36}$ $\sigma_R = 0.00028$	$R = 0.00235t^{0.25}$ $\sigma_R = 0.00022$	$R = 0.00156t^{0.32}$ $\sigma_R = 0.00013$
(III) 3/16-Inch Ceramic Triangles at 15g	$R = 0.00499t^{0.34}$ $\sigma_R = 0.00039$	$R = 0.00289t^{0.40}$ $\sigma_R = 0.00022$	$R = 0.00280t^{0.31}$ $\sigma_R = 0.00016$
(IV) Al_2O_3 N24 at 15g	$R = 0.00148t^{0.36}$ $\sigma_R = 0.00034$	$R = 0.00085t^{0.34}$ $\sigma_R = 0.00010$	$R = 0.00054t^{0.36}$ $\sigma_R = 0.00022$
(V) Al_2O_3 N14 at 20g	$R = 0.00084t^{0.53}$ $\sigma_R = 0.00046$	$R = 0.00082t^{0.47}$ $\sigma_R = 0.00029$	$R = 0.00064t^{0.43}$ $\sigma_R = 0.00033$
(VI) Al_2O_3 N14 at 5g	$R = 0.00069t^{0.48}$ $\sigma_R = 0.00012$	$R = 0.00065t^{0.49}$ $\sigma_R = 0.00004$	$R = 0.00114t^{0.17}$ $\sigma_R = 0.00006$
(VII) 1/4-Inch Plastic Pyramids at 15g	$R = 0.00348t^{0.35}$ $\sigma_R = 0.00126$	$R = 0.00269t^{0.32}$ $\sigma_R = 0.00046$	$R = 0.00192t^{0.29}$ $\sigma_R = 0.00073$

*0.001 inch = 25.4 μm. Radius (R) is in inches, where t = time in minutes. Standard deviation (σ_R) is in inches.

The data in Table 6 are the rates of change of radius per minute at 5, 20, and 30 minutes.

Although these rates are valid for comparison, the estimated time to obtain a 2.0 or 5.0 mil radius from the fitted equations will show processes are too fast and would be difficult to control, while others are too slow, requiring more time than would be desirable. Values greater than 60 minutes are extrapolated and their accuracy will decrease with increased projection beyond 60 minutes. The plotted curves, Figure 4 through 24, may be used to estimate the time to obtain a desired radius if it is obtained in 60 minutes or less.

It is frequently desirable to know how long one can run before a 0.002 or 0.005 inch (50.8 or 127.0 μm) radius is reached. Table 7 presents such information.

Tables 6 and 7 show that the process for a given radius part, material, and part size must be chosen carefully. A process that will yield a 0.002 inch (50.8 μm) radius in a desirable time may require an excessive time to generate a 0.005 inch (127.0 μm) radius. Conversely, a process that gives a reasonable time to generate a 0.005 inch radius may be too rapid for good control of a 0.002 inch radius for the same size part and material. The change in time for a change in radius is not the same ratio for different size parts, materials, or processes. The time increases with a reduction in size or hardness of the material. The size effect is not the same ratio for all materials. Group VII is a fast process, second only to Group III. Group I is the third fastest. Group VI required the longest time to obtain 0.002 and 0.005 inch. An attempt was made to express the values for "a" and "b" in the fitted equation in terms of material hardness and specimen size for each process, using a linear model. The fit was poor. A more flexible model, requiring more than three levels of hardness and three specimen sizes, is necessary and hence is beyond the capability of the existing data.

Repeatability of Stock Loss

In the second test, 30 each of the 0.5-inch-diameter (12.7 mm) cylinders of aluminum and stainless steel were measured before and after Harperizing. As before, results were recorded to the nearest 0.00020 inch (0.5 μm). In this instance, the part was rotated to find the minimum dimension at the center of the part. (In the previous test no attempt was made to find the minimum reading.) The parts were measured twice after Harperizing to establish the measurement error.

The specimens were Harperized at 15 g's in N14 aluminum oxide nuggets and 1A-1 compound for 20 minutes.

Table 6. Rates of Change in Radius (Microinches per Minute)

Group and Time (min)		Workpiece Material 303 Se SS			1018 Steel			6061-T6 Aluminum		
		Part Diameter (Mils)								
		500	250	115	500	250	115	500	250	115
I	5	218	157	108	264	177	120	195	156	128
	20	103	70	49	121	75	53	72	59	44
	30	83	56	39	97	58	42	54	44	39
II	5	152	105	39	240	148	84	378	176	167
	20	74	50	15	101	65	40	156	62	65
	30	60	40	12	79	51	32	120	46	49
III	5	377	295	179	479	381	207	588	442	306
	20	158	120	75	203	166	84	235	192	114
	30	122	92	58	158	130	65	180	151	86
IV	5	147	89	37	190	102	60	189	96	72
	20	72	46	22	89	52	33	78	38	30
	30	58	38	19	71	43	28	60	29	23
V	5	181	128	80	228	156	92	210	162	109
	20	82	82	73	101	79	40	109	77	50
	30	65	72	71	79	65	32	90	62	39
VI	5	125	88	57	157	108	72	152	114	51
	20	74	45	34	71	49	38	76	52	16
	30	64	37	29	49	39	31	62	41	12
VII	5	255	212	89	320	250	112	435	287	180
	20	98	85	39	127	103	43	178	112	69
	30	74	65	30	97	80	33	137	85	51

*1 Microinch = 25.4 nm.

The results of this study are shown in Table 8. The average stock loss for aluminum was 0.000072 inch (1.83 μm) and for stainless steel it was 0.000049 inch (1.24 μm). From the statistics shown, one can be 95 percent confident that 95 percent of all losses produced on stainless steel specimens under identical conditions will fall within the limits -0.000049, ±0.000070 inch (-1.24 ±1.78 μm).

Table 7. Time Required to Produce a Given Radius

Group and Part Diameter (Inch)*	Material 303 Se SS		1018 Steel		6061-T6 Aluminum	
	Time (Minutes) to Indicated Radius (Inch)*					
	0.002	0.005	0.002	0.005	0.002	0.005
I 0.5	3.46	25.36	1.98	15.91	0.70	18.46
0.25	5.89	52.15	3.37	37.61	2.04	43.25
0.115	14.68	123.64	10.59	98.97	6.12	90.68
II 0.5	8.40	56.58	1.51	16.84	0.33	4.17
0.25	14.75	108.09	5.95	58.80	0.52	20.49
0.115	196.56	2694.36	28.26	207.16	2.17	38.09
III 0.5	0.40	4.75	0.24	2.70	0.07	1.01
0.25	0.59	8.05	0.57	5.60	0.40	3.94
0.115	3.09	35.58	1.65	22.56	0.34	6.49
IV 0.5	8.65	58.35	4.37	33.48	2.31	29.42
0.25	25.42	143.21	20.11	117.14	12.86	198.23
0.115	100.70	452.26	52.14	260.23	36.13	444.79
V 0.5	4.40	37.50	2.30	21.00	5.10	28.70
0.25	15.20	58.80	8.40	51.10	8.40	51.10
0.115	26.00	69.50	21.40	188.40	14.30	121.00
VI 0.5	15.20	66.20	8.00	52.20	9.40	64.30
0.25	26.20	156.00	15.00	121.00	13.20	109.30
0.115	54.20	238.00	38.20	210.80	26.90	5714.00
VII 0.5	0.52	9.70	0.36	5.60	0.21	2.80
0.25	1.40	20.30	1.10	13.90	0.40	7.00
0.115	21.20	213.10	7.40	133.00	1.10	26.10

*0.1 inch = 2.54 mm.

The amount of stock lost was a linear function of the size of the specimen. The equations defining the loss are

$$D_A - 0.48900 = 4.4294 \times 10^{-5} + 0.7724(D_i - 0.48900) \quad (8)$$

for aluminum

Table 8. Repeatability of Size Change

Measurement	Stock Loss and Confidence Intervals: Aluminum (Inch x 10^{-6}) (μm)	Stainless Steel (Inch x 10^{-6}) (μm)
With Measurement Error	-72 ±316 (-1.83 ±8.0)	-49 ±89 (-1.24 ±2.25)
Without Measurement Error	-72 ±268 (-1.83 ±6.8)	-49 ±70 (-1.24 ±1.78)
Measurement Error	72 (-1.83)	24 (0.61)

$$D_A - 0.48900 = -9.2744 \times 10^{-5} + 1.0652(D_i - 0.48900) \quad (9)$$

for stainless steel

where D_i is the initial diameter and D_A is the diameter after Harperizing.

These equations reduce to

$$D_A = 0.111242 + 0.7724\ D_i \quad (10)$$

for aluminum and

$$D_A = -0.031795 + 1.0652\ D_i \quad (11)$$

for stainless steel.

Note that these equations are only valid for diameters in the vicinity of 0.489 inch (12.42 mm), lengths of 0.5 inch (12.7 mm) and the Harperizing conditions described. Suitable conversions must be made if diameters are expressed in metric dimensions.

In many cases, the standard deviation of diameter measurement of a group of parts after Harperizing was smaller than initial group standard deviation, resulting in more consistent parts. This can be explained by the linear trend described above. The process takes more stock off a large part than one slightly smaller.

This can also be shown statistically. If a group of parts having a standard deviation of σ_A are subjected to a process which also affects dimensions in a random manner, then the standard deviation of the group of parts coming out of this process will be

$$\sigma_F = \sigma_A^2 + \sigma_B^2 - 2r\sigma_A\sigma_B \tag{12}$$

where

σ_F = final standard deviation of the group,

σ_B = final standard deviation of the process,

σ_A = final standard deviation of initial parts, and

r = correlation coefficient of before and after measurements.

In a truly random process, the before and after measurements are not correlated; thus, r = 0 and σ_F will always be larger than σ_A. The linear trend described above is a direct indication that correlation exists. Therefore, if r is positive, σ_F can be smaller than σ_A. As a result, the final parts can be more consistent than the initial parts. Note that the basic size will still change, but there will be less variability in the measurements.

As an example, from the data of this test, the initial standard deviation in aluminum was 253.727 microinches (0.643 μm); after the process, σ_F was 235.807 microinches (0.599 μm) and r was 0.8311. Substituting these values into the previous equation, it is found that the standard deviation of the process under these conditions is either 400 or 22 microinches (1.016 or 0.055 μm); the solution to the quadratic equation has two positive roots in this case. Based on a number of other studies of actual piece parts it is apparent that the repeatability (σ_B) is on the order of 22 microinches.

The observed effect of decreasing size variability has been detected on about 50 percent of all batches studied. Roughly 25 percent exhibited a slight increase in variability and the remainder exhibited no change. In most cases, however, the improvement or worsening was small (on the order of 0.000010 inch or 0.254 μm).

Effect of Burr Size on Edge Radius

In the third study, simulated burrs were used to determine how burr height and thickness affect the deburring process. Cylinders 0.375 inch (9.525 mm) in length of 303 Se stainless steel were used. Discs punched from 0.001- to 0.005-inch-thick (25.4 to

127.0 μm) 302 stainless steel were spot welded to the end of each cylinder to simulate a burr. All discs were 0.375 inch in diameter and the cylinders were ground to diameters which provided from 0.001- to 0.010-inch-high (25.4 to 254.0 μm) simulated burrs.

Height of these simulated burrs was measured optically by rotating the part to find the highest projection from the surface. Because the discs were not accurately centered, some runout existed which made it necessary to measure the highest projection. All measurements were made to the nearest 0.0001 inch. Burr height was measured after each 5-minute Harperizer cycle. The parts were subjected to the N14 aluminum oxide nuggets and the 1A-1 compound at 15 g's. As in all studies recorded in this report, the specimens and media were covered with water.

Although the initial burr height varied considerably, the rate of reduction in burr height depended upon the thickness and contour. Consequently, the data was regrouped into like thickness and converted into change in height at time "t" minutes, using the equation

$$\Delta h_t = h_o - h_t \qquad (13)$$

where

Δh_t = change in height,

h_o = initial burr height, and

h_t = burr height at "t" minutes.

Nine specimens of 0.001- or 0.002-inch-thick burrs were deburred and a radius generated at the edge. This was reported as a radius instead of height. These values were converted into a negative height.

The high point on the burr is a point of symmetry (Figure 27) which is also used as the reference point. When the burr is removed, a radius is generated which is converted to a negative height in terms of R.

$$h = -0.176 R \qquad (14)$$

The following model was used to fit the data:

$$\Delta h = h_o - h_t = a\ w^b\ t^{cw^2} \qquad (15)$$

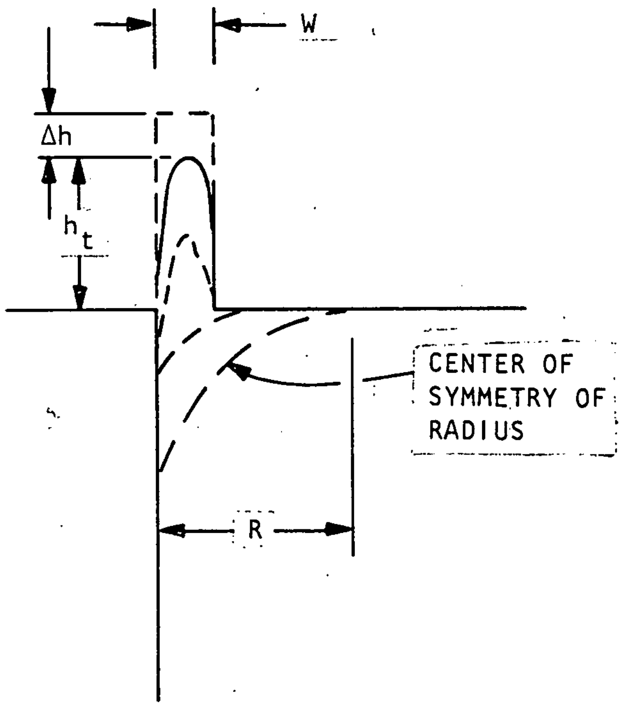


Figure 27. Conceptual View of Change in Burr Height

where

w = width of burr in mils,

b = constant, and

c = constant.

This model adjusts for burr width; a burr twice as thick as another does not take twice the time for the same reduction in height. Also, thin burrs have more time effect than thick burrs; therefore, the power of time "t" includes the burr width "w" to a power.

The resulting equation was obtained omitting the reported values for t = 5 minutes (the inspector recorded average height rather than maximum height at this time interval).

$$\Delta h = h_o - h_t = 4.69w^{-1.2}\ t^{0.713w^{0.169}} \times 10^{-4} \text{ inch.} \qquad (16)$$

The standard error of the estimate was $\sigma\Delta h$ = 0.000195 inch (omitting t = 5 minutes). Note that w must be expressed in terms of 0.001 inch units (i.e., 0.00175 = 1.75). The terms h and h_o are given in inch units.

Table 9 presents the mean values for change in burr height with time. The calculated values from the above fitted equation are shown in parenthesis in that table. Typical data calculated from Equation 16 is shown in Figure 28. The results from Equation 16 can be used to estimate the height of burr after "t" minutes harperizing or the time required to remove the burr (i.e., t for h = 0).

For example, what is the estimated burr height after 12 minutes of harperizing under the conditions of this test if the initial burr height h_o = 0.0027 inch, and initial burr width or thickness (w) = 0.00175 inch?

Under these conditions, Equation 16 becomes

$$h = 27 \times 10^{-4} - 2.396t^{0.784} \times 10^{-4}$$

and at t = 12 minutes,

$$h = 27 \times 10^{-4} - 16.8 \times 10^{-4}$$

$$= 10.2 \times 10^{-4} \text{ inches burr height after 12 minutes Harperizing.}$$

What, then, would be the estimated time to remove the burr, that is, to obtain h = 0 or $\Delta h = h_o$?

By rearranging Equation 16, an expression for the time (t) required to reach a burr height of h_t can be obtained:

$$\frac{10000(h_o - h_t)}{4.69w^{-1.200}} = t^{0.713w^{0.169}}$$

$$\ln \frac{10000(h_o - h_t)}{4.69w^{-1.200}} = 0.713w^{0.169} \ln t$$

$$\frac{\ln \dfrac{10000(h_o - h_t)}{4.69w^{-1.200}}}{0.713w^{0.169}} = \ln t$$

Table 9. Mean Change in Burr Height

Time (min)	Thickness (w) (Inch) and Δh*				
	0.001 $4.69t^{0.713}$	0.002 $2.03t^{0.802}$	0.003 $1.24t^{0.859}$	0.004 $0.88t^{0.901}$	0.005 $0.673t^{0.936}$
5	19.5 (14.8)**	15.3 (7.4)	14.0 (4.9)	8.5 (3.75)	9.6 (3.04)
10	23.0 (24.2)	14.3 (12.9)	10.1 (9.0)	6.9 (7.0)	5.9 (5.8)
15	32.0 (32.3)	16.8 (17.8)	13.5 (12.7)	9.5 (10.1)	6.8 (8.5)
20	39.7 (39.7)	24.9 (22.4)	18.6 (16.3)	13.5 (13.08)	10.5 (11.1)
25	41.7 (46.5)	32.2 (26.8)	20.9 (19.7)	15.5 (16.0)	13.1 (13.4)

*0.001 inch = 25.4 μm.
**First number is measured data; calculated data is in parentheses. Data is in inches x 10^{-4}.

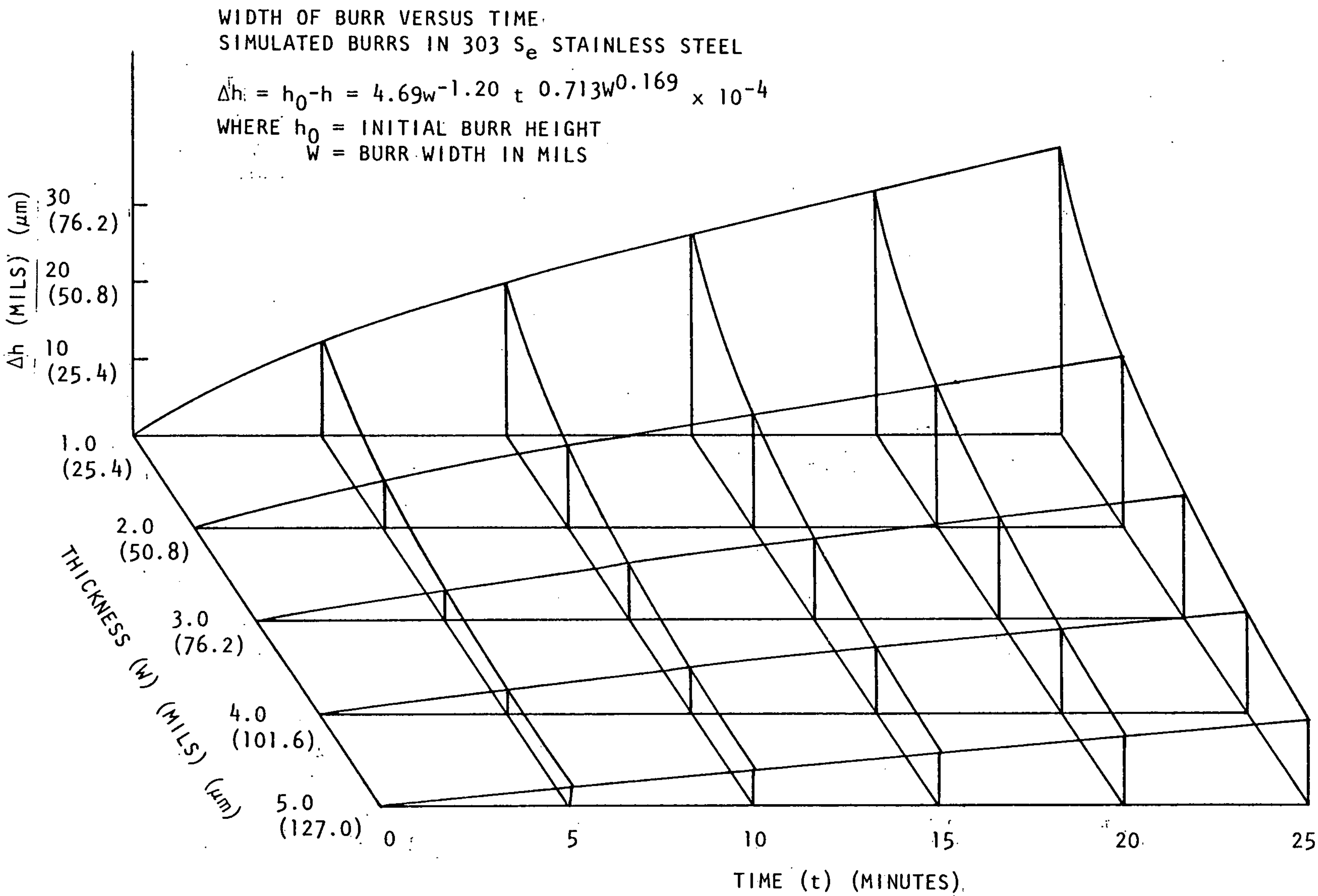


Figure 28. Reduction in Burr Height by Harperizing

Finally,

$$t = \exp\left[\frac{\ln\left(\frac{10000\ h_o}{4.69w^{-1.200}}\right)}{0.713w^{0.169}}\right]$$

substituting $w = 1.75$ and $h_o = 0.0027$, one finds that

$t = 22$ minutes to remove the burr.

The fit for the exponential model to the mean data is relatively good, as has been found in previous studies. A change in the harperizing process will change the constants in the equation; the response Δh will also be changed.

Observations on Production Parts

Harperizing has been used to deburr over 150 different components at Bendix. The materials represented by these components include brass, 300 series stainless steels, 17-4 PH stainless steel, Kovar, Paliney, beryllium-copper, aluminum, and ceramics. As seen in Figure 29, these parts have a wide variety of shapes. The production observations support the dimensional changes described on preceding pages.

Consider the parts shown in Figure 30. These parts are shown next to a United States dime. A 15-minute Harperize cycle in 1/4 inch (6.34 mm) plastic pyramids, N24 aluminum oxide nuggets, and 1A-1 compound at 15 g's removed 0.0003 inch (7.62 μm) stock from one dimension which has a tolerance of only 0.0004 inch (1.02 μm). It is obvious that such a part must be intentionally machined oversize if print dimensions are to be maintained. This part is made from 17-4 PH (H900) stainless steel.

A 20-minute cycle in N14 nuggets at 30 g's removed 0.00008 inch (2.0 μm) from the 0.025 inch (635 μm) 17-4 PH stainless steel journals shown in Figure 31.

A change of 0.0005 inch (12.7 μm) occurred on the diameter of the fine edge blanked aluminum spacer shown in Figure 32. These parts were deburred in 20 minutes at 15 g's, using 3/16 triangles and 1A-1 compound. The burrs on this part were 0.0035 inch (88.9 μm) thick at their root and 0.008 inch (20.3 μm) high; the final edge radius was 0.010 inch (0.254 mm).

Although holes smaller than 0.040 inch (1 mm) do not usually deburr completely, those shown in Figure 33 did. This powder metal ferrite core is soft enough that abrasive particles can effectively

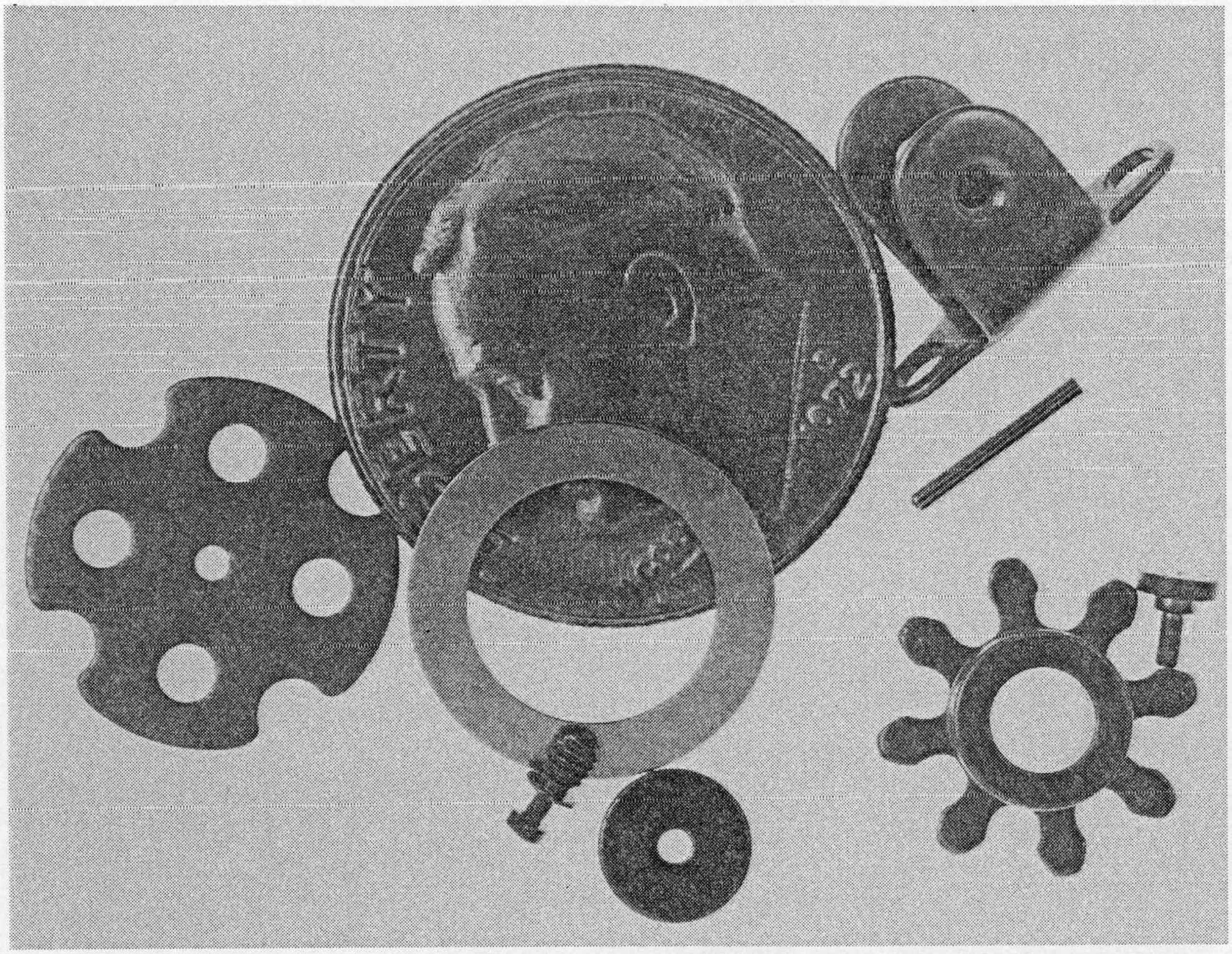


Figure 29. Production Parts That Have Been Harperized

produce a small radius on the four 0.020-inch-diameter (0.51 mm) holes. A stock loss of 0.003 inch (76.2 μm) occurs in the center hole using N14 nuggets and 1A-1 at 15 g's for 20 minutes. A 2-hour run in 3/16-inch ceramic bonded triangles produced a 0.020 inch (0.5 mm) radius on a 3-inch-diameter by 0.5-inch-thick (76.2 by 12.7 mm) ring.

Effects of Piece Part Geometry

As in all loose abrasive processes, deburring aggressiveness is a function of part size and media size and shape. As an example, if slots and steps are too shallow, complete deburring may not occur (Figure 34). In this case the step height "H" must be greater than the media radius R_S for deburring to be effective. If triangular shaped media is used, the slot width must exceed

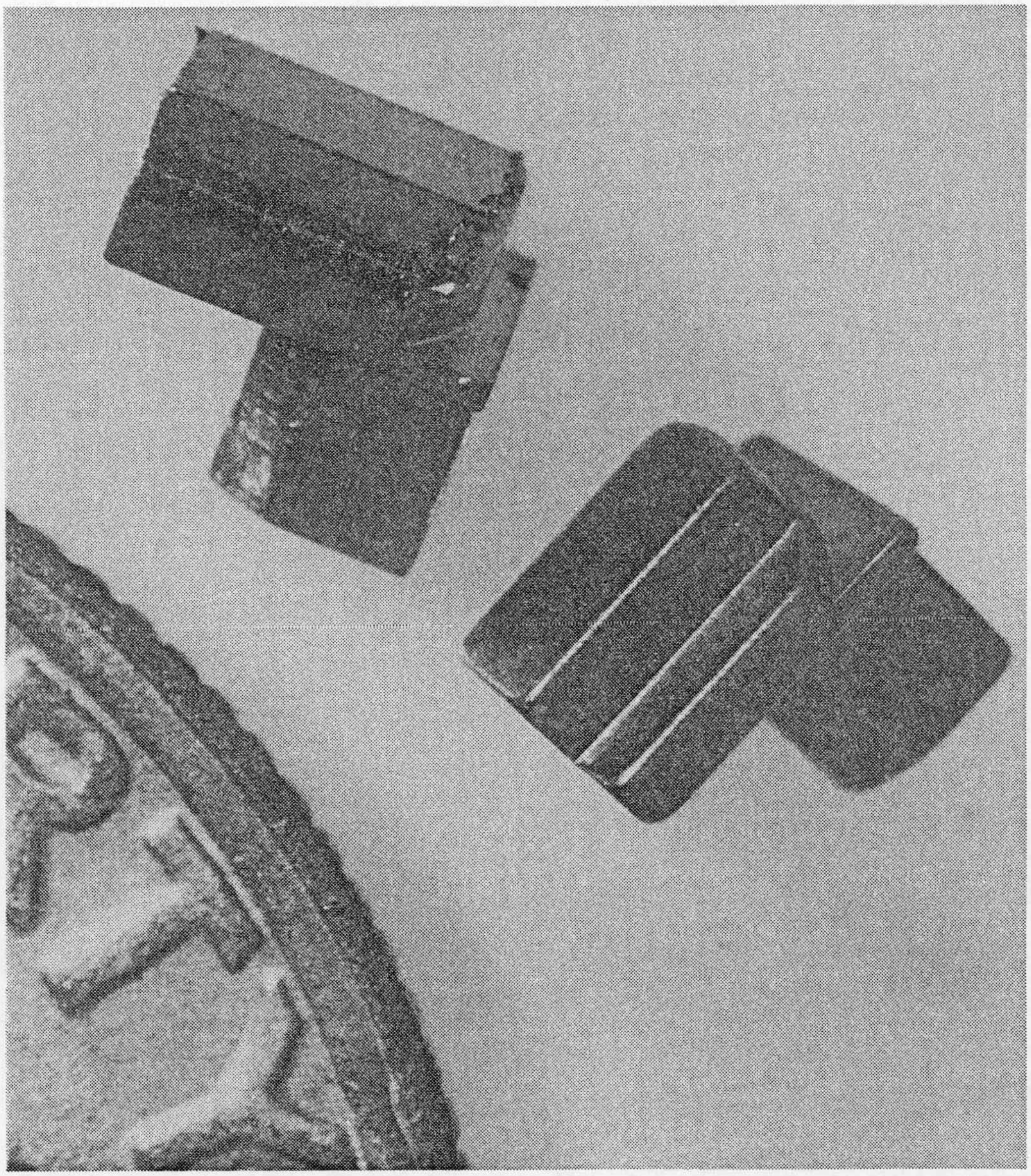


Figure 30. Miniature Stainless Steel Blocks Before and After Harperizing

$2R_S$. (Actually, the slot width should exceed 6 R_S to prevent media lodging in holes.) If these features were the bottom of a counterbore, no deburring action would occur because the media cannot readily move out of blind pockets.

While reducing media size may seem an obvious solution, the deburring forces decrease rapidly with media size. For most purposes an N14 nugget is as small as one can easily use [roughly a particle of 0.060 inch (1.51 mm)].

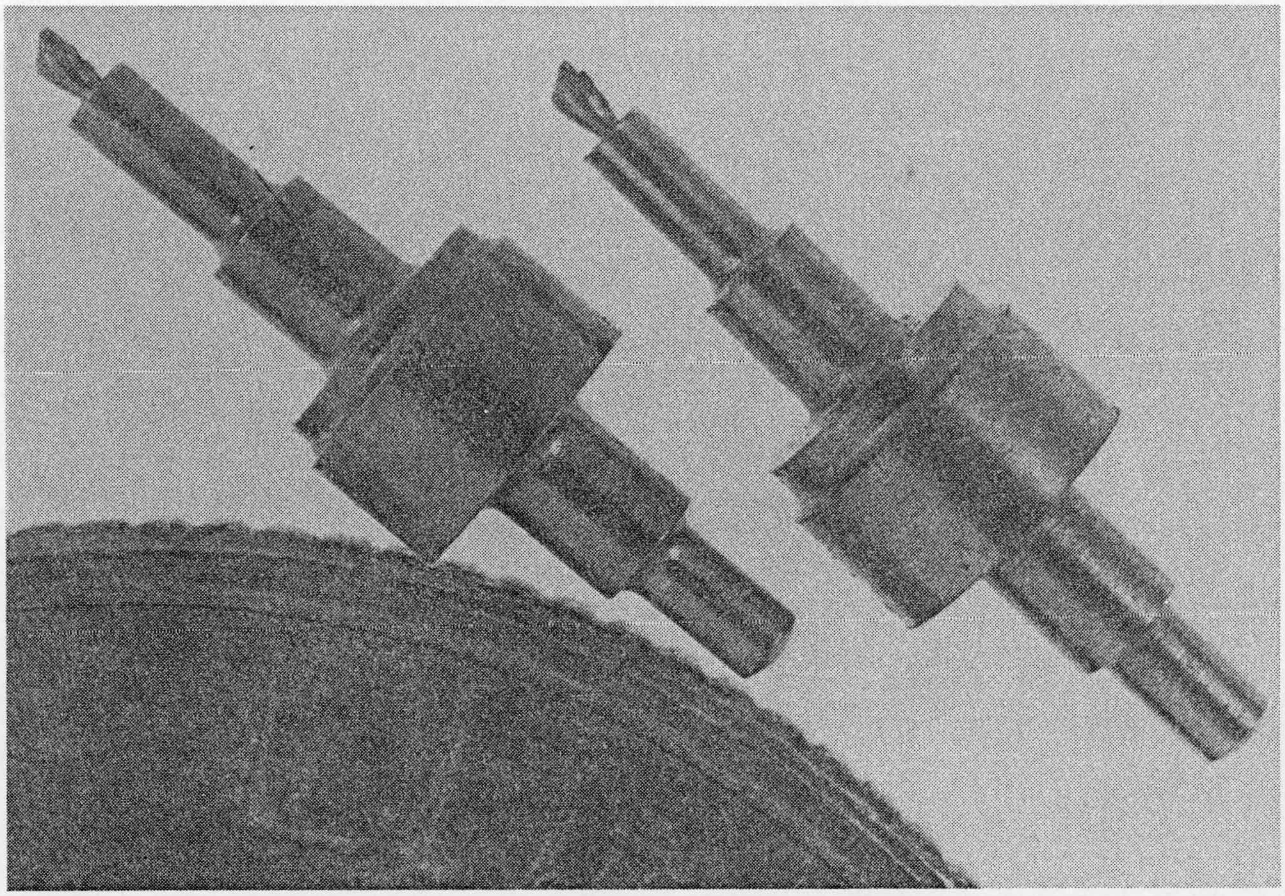


Figure 31. Stainless Steel Pinions Before and After Harperizing

As reported elsewhere[3] radiusing is a function of the angle between the surfaces (Figure 35). Provided the part does not shield the media an edge angle of 120 degrees can develop a radius 10 to 20 times larger than an edge of 30 degrees (Figure 36). While the large angle develops a radius faster, it is also much more difficult to control its repeatability.

Large parts tend to bang together in small barrels. For this reason it is not advisable to deburr parts larger than 1 inch (25.4 mm) at speeds above 5 g's in the machine used in this study.

Long, thin, soft parts also tend to become distorted in the Harperizer. In one instance, some 3-inch-long (76.2 mm) wires were actually tied in knots after Harperizing. While lower speeds reduce the tendency for damage, the potential is always there for large parts in small barrels. The initial jerk as the machine begins to rotate is sufficient to dislodge shock and

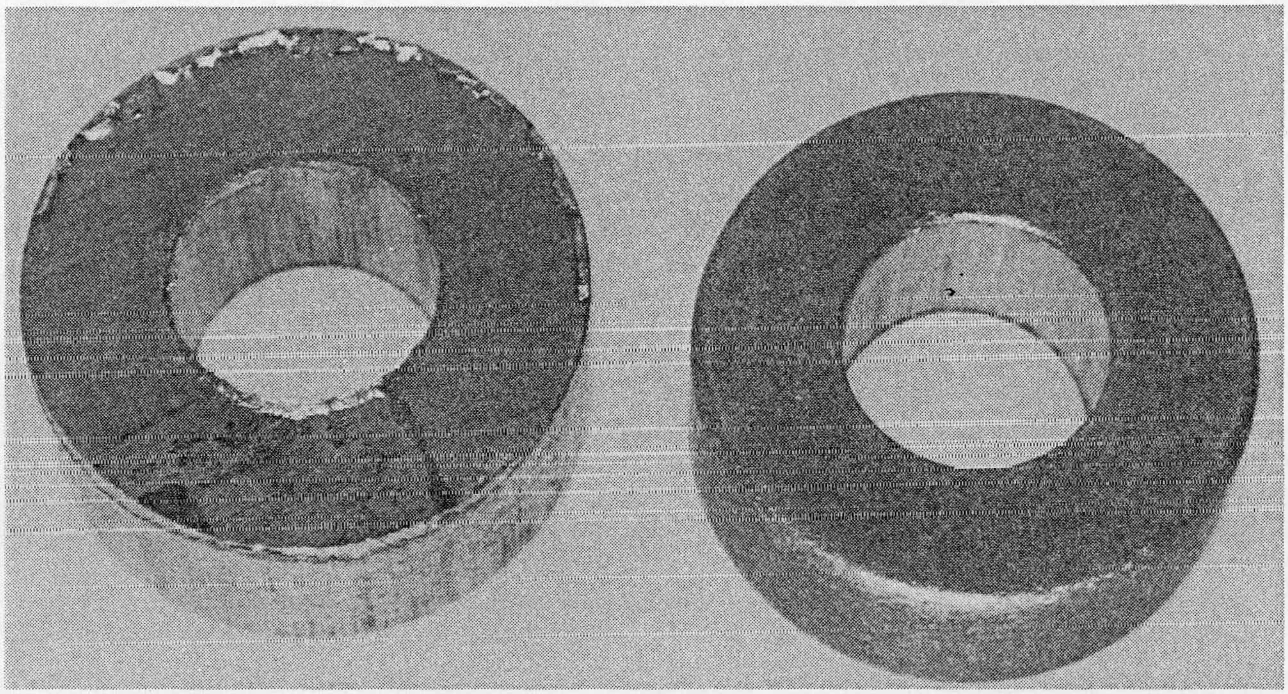


Figure 32. Aluminum Spacers Before and After Harperizing

acceleration indicators (Impact-O-Graph Shock Monitor, Impact-O-Graph Division, Torq. Engineered Products, Inc., Bedford, Ohio) set for 30 g's even though the machine is set for 5 g's.

One of the major limitations of the process for use on precision miniature short-run parts is that it may take 2 to 4 hours to separate nonmagnetic parts from media of roughly the same size. While this is a problem for only a few shapes and sizes, it can be a limiting factor to usefulness.

Harperizing Effects on Subsequent Processes

All loose abrasive processes beat minute particles of abrasive media into part surfaces. While these are not visible under 200X magnification, they can be detected by Auger Electron Spectrometers. This contamination which is not removed by conventional cleaning processes, can cause blow holes or stress concentrations in welded joints. It can also prevent good braze joints (aluminum oxide, which is the most commonly used abrasive, is often intentionally used on tooling to prevent braze wetting on tool surfaces). Recent studies indicate that the probability of adhesion failures increases when difficult-to-plate materials have such contamination

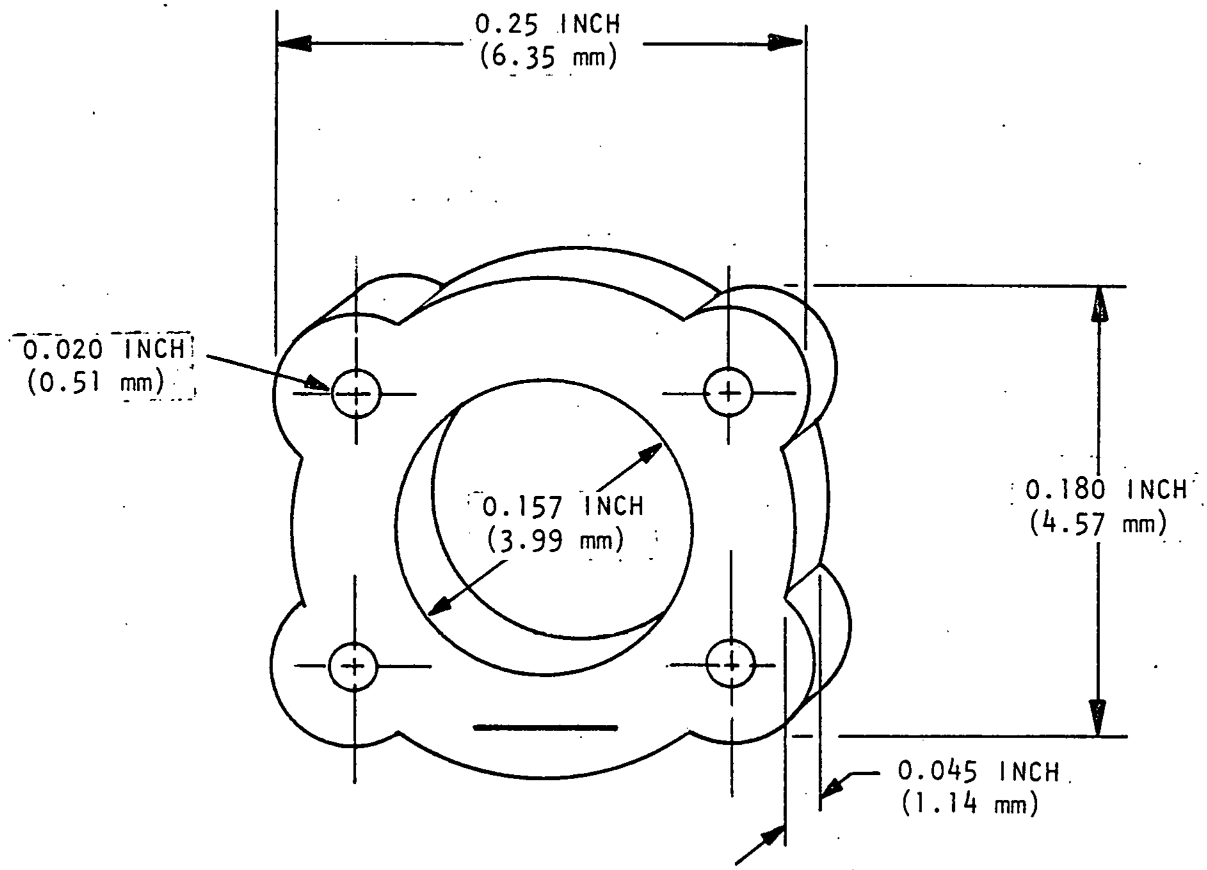


Figure 33. Powder Metal Part

on them. The barrels used in Harperizing have enough aluminum oxide abrasive in their surfaces to contaminate several lots of parts. For this reason it is necessary to have two sets of barrels so that one set is only used for non-aluminum oxide abrasives.

While aluminum oxide media is the worst offender, silicon carbide and quartz base materials also cause some problems but on a smaller scale. Dolamite (magnesium calcium carbonate) is the only material studied which could be cleaned from parts entirely without chemically etching parts. Plastic media left a thin film of plastic on the parts studied.

Since most parts are not plated or welded, aluminum oxide media does not present a problem. Because it lasts 10 to 100 times longer than other media, it is generally the most economical. Silicon carbide and dolamite break down quickly into small pieces which lodge in small holes, grooves, and similar crevices. No media appears to create adhesion problems for dry film lubricants when they are applied after Harperizing.

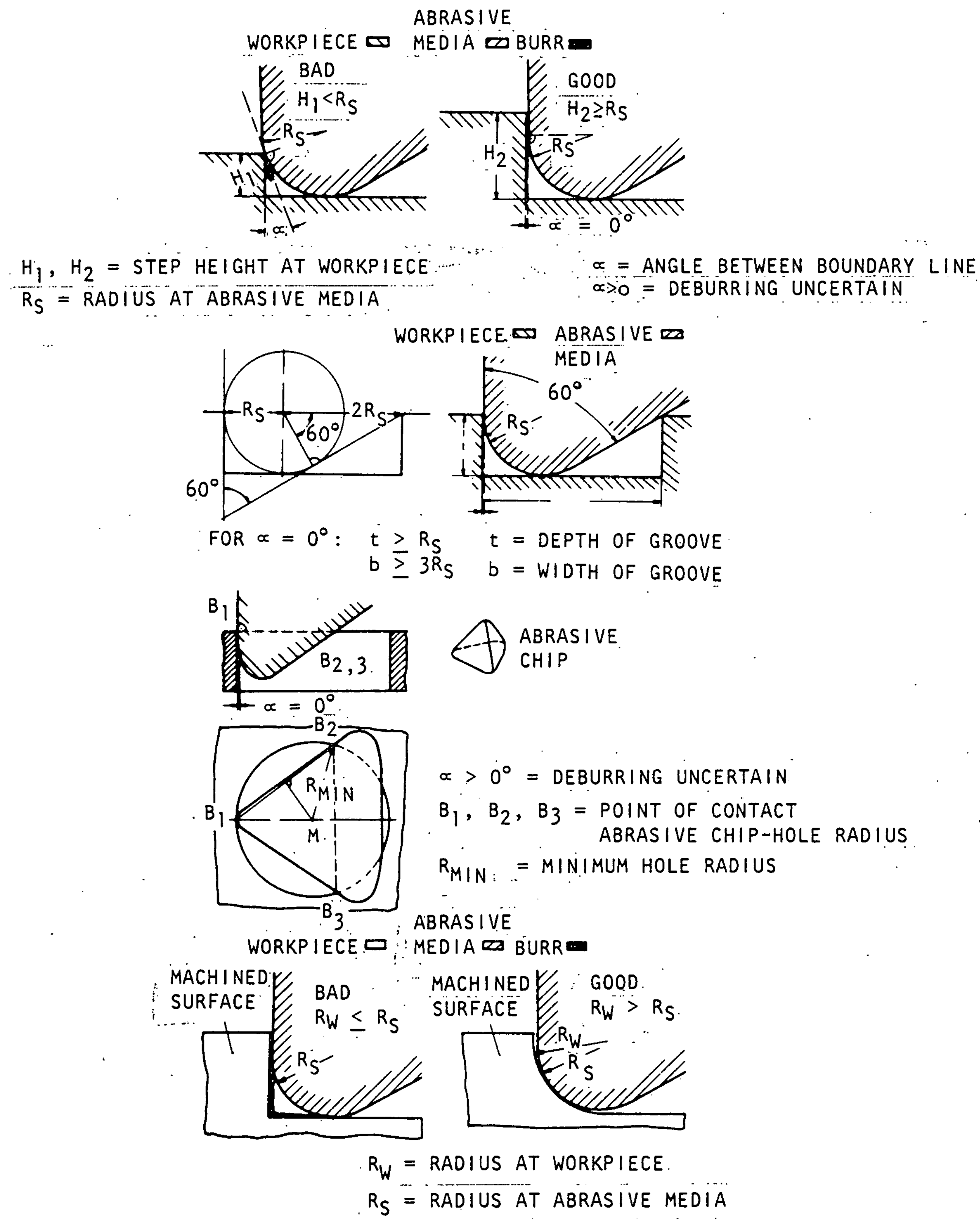
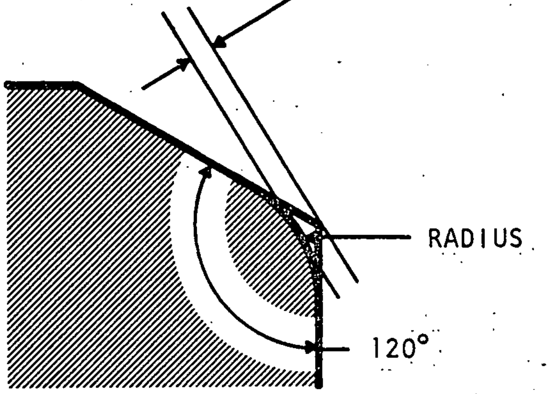
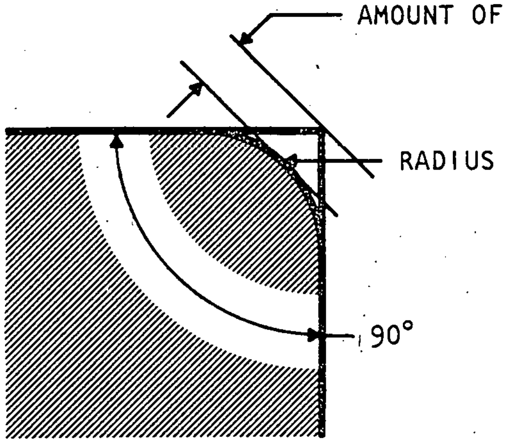


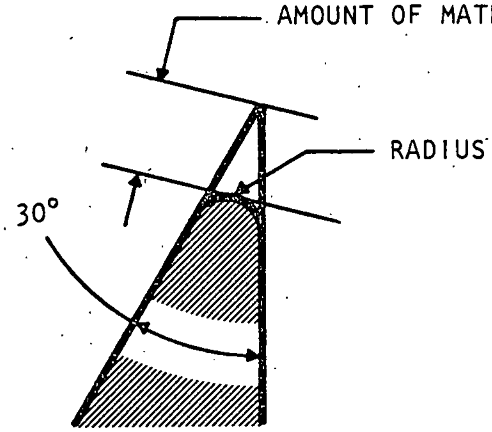
Figure 34. Effect of Part Geometry on Deburring



RADIUS		S	
INCH	µm	INCH	µm
0.002	50.8	0.0003	7.6
0.003	76.2	0.0004	10.2
0.005	127.0	0.0007	17.8
0.010	254.0	0.0015	38.1
0.015	381.0	0.0022	55.9



RADIUS		S	
INCH	µm	INCH	µm
0.002	50.8	0.0008	20.3
0.003	76.2	0.0012	30.5
0.005	127.0	0.0021	53.3
0.010	254.0	0.0041	104.1
0.015	381.0	0.0062	157.5



RADIUS		S	
INCH	µm	INCH	µm
0.002	50.8	0.0077	195.6
0.003	76.2	0.0116	294.6
0.005	127.0	0.0194	492.8
0.010	254.0	0.0387	983.0
0.015	381.0	0.0581	1475.7

Figure 35. Effect of Geometry on Edge Radiusing

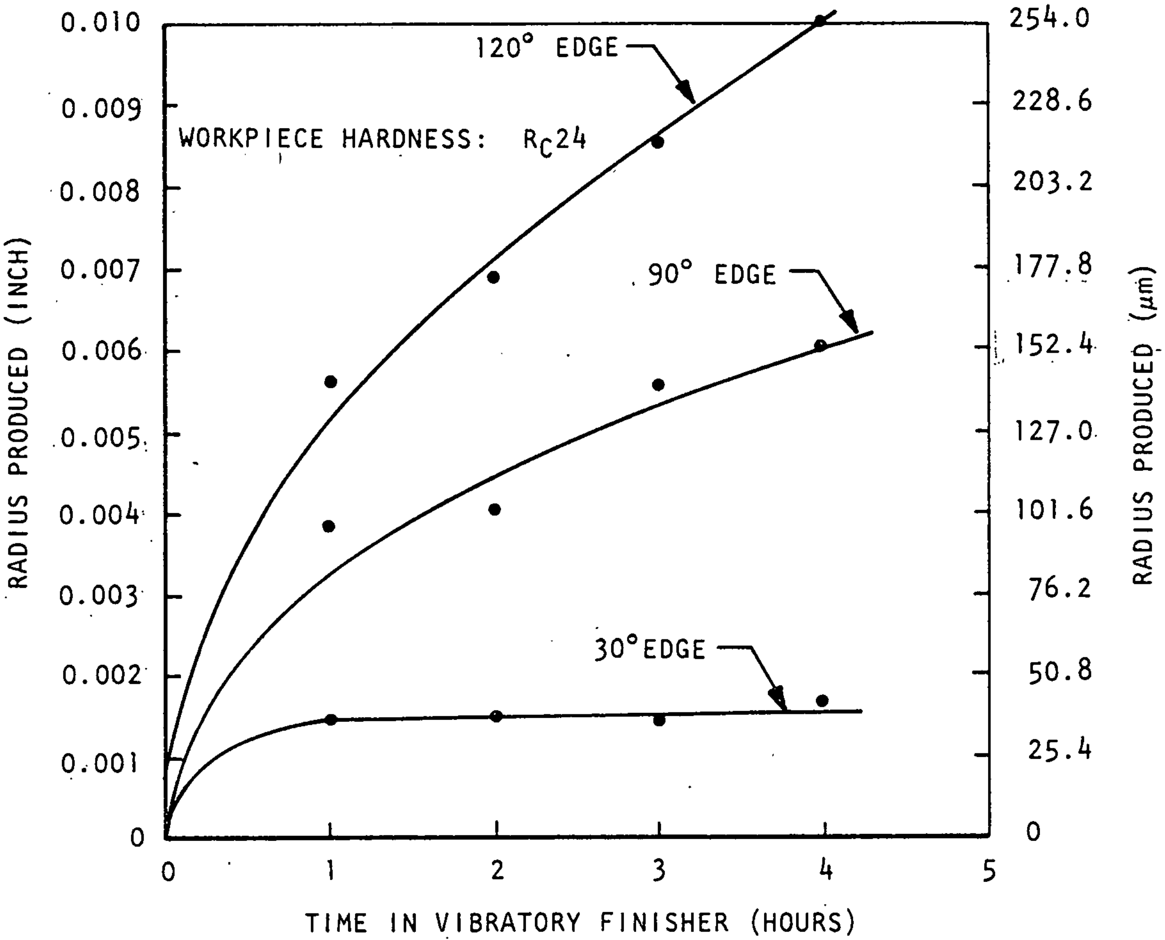


Figure 36. Effect of Edge Angle and Vibration Time on Edge Radiusing of Phosphor Bronze Workpiece

Harperizing has several positive advantages that are often overlooked. It removes heat treat scale or tints that may interefere with appearance or passivation. It removes machining oils and die lubricants (the abrasive compound contains a large proportion of soap). It can be used to "machine" oversize parts to a smaller size. It imparts residual compressive stresses which generally improve fatigue life. In some cases this can also result in part distortion. It can produce finishes as fine as 2 microinch AA (0.05 µm). In general it improves finishes while deburring but further improvements require special burnishing cycles.

While fine surface finishes may not be necessary one user has pointed out that they do have two beneficial side effects. Every individual who handles the parts afterwards associates fine finishes with precision and high quality. This in turn causes most individuals to treat such parts with more care. Secondly parts with fine finishes are easier to clean since fewer crevices and scratches exist on them to trap soils and contaminants.

Evaluation of Published Literature

Of the literature published to date not a single reference describes the burr removed by Harperizing. Matsunaga's work[4-6] presents data on stock loss which is useful for general comparisons. Lur'e and Sinotin[8] present data on weight losses and surface finish changes as a function of centrifugal forces on Soviet steels. Hignett's recent paper[9] and one by Schmolz[10] provide some useful general facts.

ACCOMPLISHMENTS

The effect of centrifugal barrel finishing parameters on surface finish, edge radius, and dimensional changes has been determined. The influence of burr size on the time required for deburring has been noted, and typical production limitations and applications have been described. Guidelines for the implementation of this process have also been prepared (Appendix A).

FUTURE WORK

Although no future work is planned as part of this process development project, some additional documentation of process effects on size changes from this process will be made. Because of the increasing need to produce surface finishes of 16 microinches (0.406 μm), a future study would be desirable on the centrifugal barrel finishing parameters required to produce such finishes.

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[4]M. Matsunaga and H. Kobayashi, "Some Experiments on Centrifugal Barrel Finishing," *Metal Finishing*, Vol. 64, No. 5, 1966, pp 57-60.

[5]M. Matsunaga, "Theory and Experiments on Centrifugal Barrel Finishing," *International Journal of Production Research*, Vol. 5, No. 4, 1967, pp 275-287.

[6]M. Matsunaga and Y. Hagiuda, *Researches on Barrel Finishing*, Report of The Institute of Industrial Science, The University of Tokyo, Vol. 17, No. 4 (Serial No. 111), February, 1967, pp 145-154.

[7]F. Schafer, *Product Design Influences on Deburring*, SME Paper MR 75-483, 1975.

[8]G. B. Lur'e and A. P. Sinotin, "Tumbling of Workpieces in Drums with a Planetary Rotation," *Russian Engineering Journal*, Vol. 54, No. 8, 1974, pp 39-51.

[9]J. Bernard Hignett, *Capabilities and Limitations of Centrifugal Barrel Finishing*, SME Paper MR 75-834, 1975.

[10]K. Schmolz, "Centrifugal Grinding and Finishing," *Galvanotchnik*, Vol. 63, No. 4, 1972, pp 325-34 (in German).

Appendix A

GUIDELINES FOR USE OF CENTRIFUGAL BARREL TUMBLING

Table A-1. Description of Media and Abrasives Used

Bendix Code Number	Description
10651385	Al_2O_3 triangles, 3/16 by 3/16 by 1/8 inch (4.8 by 4.8 by 3.2 mm), AX90 composition
10651386	Silicon carbide triangles, 1/4 by 1/4 by 1/4 inch (6.35 mm), Fortune Industries CS-46
10651380	Al_2O_3 triangles, 3/8 by 3/8 by 1/4 inch (9.5 by 9.5 by 6.35 mm), AX90 composition
10651569	Al_2O_3 triangles, 5/8 by 5/8 by 3/16 inch (15.9 by 15.9 by 4.8 mm), AX90 composition
10651382	Al_2O_3 1/8-inch-diameter by 11/32-inch-long (3.2 by 8.7 mm) cylinders, Almco C1-8
10651383	Vitrified Al_2O_3 angle-cut cylinders, 1/4-inch diameter by 5/8-inch-long by 60°, AX90 composition
10651387	Silicon carbide triangles, 5/8 by 5/8 by 5/16 inch (15.9 by 15.9 by 7.9 mm), Fortune Industries CS-46
10651435	Al_2O_3 angle-cut cylinders, 3/16-inch diameter by 11/32-inch long by 45°, AX90 composition
10651605	Fused Al_2O_3 chip, carborundum number 6, 0.092 to 0.188 inch (2.337 to 4.775 mm)
10651566	Fused Al_2O_3 chip, carborundum number 7, 0.078 to 0.156 inch (1.981 to 3.962 mm)
10651568	Fused Al_2O_3 chip, carborundum 8 grit, 0.062 to 0.130 inch (1.575 to 3.302 mm)
10651575	Fused Al_2O_3 chip, carborundum 12 grit, 0.045 to 0.090 inch (1.143 to 2.286 mm)
10651560	Al_2O_3 chip, 14 grit, 0.040 to 0.060 inch (1.016 to 1.524 mm), Mechanical Finishing Company Number 281(R)-14
10651561	Fused Al_2O_3 chip, 24 grit, 0.020 to 0.030 inch (0.508 to 0.762 mm), Mechanical Finishing Company Number 574(R)-24
10651260	Silicon carbide chip, number 8 grit, 0.062 to 0.130 inch (1.575 to 3.302 mm)

Table A-1 Continued. Description of Media and Abrasives Used

Bendix Code Number	Description
10651521	Silicon carbide chip, number 24 grit, 0.020 to 0.030 inch (0.508 to 0.762 mm), Mechanical Finishing Company Number 655(R)-24
10651555	Plastic cones, 9/16-inch (14.3 mm) diameter, impregnated with silicon dioxide abrasive
10651556	Plastic pyramids, 1/4-inch (6.35 mm), impregnated with silicon dioxide abrasive
10651368	Carborundum 1A-1 abrasive compound (Al_2O_3)

Table A-2. Typical Weights of Abrasive Media

Media	Average Weight Per Particle (mg)
N24 Al_2O_3	1.2
N14 Al_2O_3	5.9
N12 Dolomite	15.0
3/16 Triangles	142.0
1/4 Plastic Pyramids	105.0

Table A-3. Selecting Centrifugal Barrel Finishing Conditions

---

1 Are the burrs accessible?

Yes ↓ No → Find another method

2 What media size will not lodge in holes or slots?

See Tables A-4, A-5, and Section A1 of this table

Continue

3 What conditions are to be produced?

Edge radius allowable
Dimensional change allowable from this process
Surface finish requirement (See Section A2)

Continue

4 What is the initial part condition?

Burr thickness
Burr height
Surface finish on critical surfaces (See Section A3 and Table A-6)

Continue

5 Which deburring parameters will produce the requirements of Step 3 with the conditions listed in Step 4?

(See Section A4 and Table A-7)

6 Is the part subsequently welded, plated, or used as an electrical contact?

No ↓ Yes → See Section A5

7 Are the selected conditions adequate in practice?

Yes No → See Section A6

Table A-3 Continued. Selecting Centrifugal Barrel Finishing Conditions

Section	Discussion
A1	Choosing Media Size

When selecting media it is essential to choose a size which will not lodge in holes or slots (Figure A-1). Media lodged in blind holes is often impossible to remove. Any time media is removed it has the potential of scarring the feature it was removed from or distorting thin flanges. At the very least, removing such media will increase the time required to finish parts.

The random shape media consists of media of many different sizes. Even though it is graded by size, a wide variation in size and shape exists (Figure A-2). Even the preformed shapes such as triangles and cylinders have some variation in size.

As a general rule, select media which is smaller than the part. Ideally when holes or slots are present media should be either

- Slightly larger than hole size,
- Slightly smaller than hole size, or
- One-third the diameter of the hole.

Because of media wear, the third choice is the safest with random shaped media. For preformed shapes, the first two choices are easiest to assure.

For general usage on precision miniature parts, the N14 random shaped nuggets are the most desirable size.

If hole size precludes the use of any of the media shown in Table A-2:

- Screen the media to remove oversize or undersize particles (Table A-4);
- Plug holes with rubber plugs, rubber tubing which expands when tension is released, rubber bands, or nylon line with ends expanded by heat (Note that some media in holes is not harmful if it can be easily removed.);

Table A-3 Continued. Selecting Centrifugal Barrel Finishing Conditions

Section	Discussion
	• Deburr before holes or slots are machined;
	• Purchase special size media; or
	• Purchase special screen sizes for in-house screening of media.
A2	<u>Workpiece Requirements</u>
	Centrifugal barrel finishing can maintain 0.002 inch (50.8 μm) maximum edge radii if the burr is small. A 0.005 inch (127.0 μm) maximum edge radii is a much more desirable condition to have to maintain.
	Allowable dimensional changes of at least 0.0002 inch (5.1 μm) are desirable in this process. As a lower limit, it is possible to maintain size within 0.00005 inch (1.27 μm) if burrs are small.
	Allowable surface finishes should be 32 microinch (0.81 μm) or rougher, although it appears possible that finer finishes can be produced or maintained.
	Corner radii (the intersection of three or more surfaces) (Figure A-3) will be 3 to 5 times larger than edge radii.
	When a workpiece has edges with several different requirements, the centrifugal barrel process should be based on the most tightly toleranced features.
	Note: Internal features will not receive as much action as external features.
A3	<u>Initial Part Conditions</u>
	Centrifugal barrel finishing can roughen surfaces which were initially 8 or 16 microinch (0.20 or 0.41 μm).
	Deburring conditions are obviously dependent on the size of the burrs to be removed.
	If burr size is not known the values used in Table A-6 will provide some guidance.

Table A-3 Continued. Selecting Centrifugal Barrel Finishing Conditions

Section	Discussion
A4	Burr size, allowable stock loss, and maximum allowable edge radii are the most significant factors in determining which combination of parameters will produce acceptable results. Burr location and workpiece geometry are also important, but at this time data is not available to indicate their quantitative significance. Recommended centrifugal barrel finishing parameters are shown in Table A-7. These recommendations are based on the data shown in Figures 4 through 26, the study of effects of burr size, and production experience. As seen in Table A-7, it is not possible to remove burrs 0.005 by 0.005 inch (127 x 127 μm) while maintaining a 0.00005 inch (1.27 μm) maximum stock loss. These recommendations indicate the most aggressive combinations which can be used. In some cases it may be possible to lower the time, g level, or media size and still produce the desired results. With the exception of large allowable stock losses, conditions indicated should be the condition tried. If the recommendations are not quite sufficient, changes should be made using the list of problems and solutions given in Section A6.
A5	Aluminum oxide media contributes to blow holes and stress concentrations in welded joints. As such it is desirable to use other materials when such parts have to be deburred. Silicon carbide or dolamite are acceptable alternate materials. Brazing and soldering are also affected by minute aluminum oxide particles. Solder will not adhere to a surface having such particles in or on it. The probability of plating adhesion failures increases when aluminum oxide is present on surfaces. This may not be a significant problem on copper base alloys since they activate easily. This can be a significant problem on any hard to activate material. The adhesion of solid film lubricants and the passivation of stainless steels do not appear to be affected by the presence of minute aluminum oxide particles.

Table A-3 Continued. Selecting Centrifugal Barrel Finishing Conditions

Section	Discussion
	Electrical contacts which must operate in low resistance circuits are unaffected by dolamite, but other deburring media appear to increase circuit loop resistance (CLR). Any dolamite film left on parts is easily removed by a 10 percent solution of warm acetic acid.
A6	<u>Problems and Solutions for Deburring Stainless Steel, Beryllium Copper, and Aluminum</u>

To solve incomplete burr removal:

- Use larger media;
- Run for a longer time;
- Increase "g" level;
- Use a combination of large and small media;
- Manually remove large initial burrs;
- Use a more abrasive compound;
- Be sure the media shape is consistent with part geometry;
- Use a lighter media if burrs are bent over;
- Place the parts in a fixture; or
- Reduce the water level.

To solve surface damage, impingement, or roughness:

- Use smaller media or well-worn media;
- Reduce the cycle time;
- When using two different sizes of media, use more of the smaller size;
- Use a less abrasive compound;
- Select a more appropriate media shape;

Table A-3 Continued. Selecting Centrifugal Barrel Finishing Conditions

Section	Discussion
	• Mask sensitive areas; • Increase the water level; or • Reduce the number of parts per load. To keep the media from lodging in the piecepart: • Use sizes of media which will not lodge in holes and recesses; • Do not use irregularly-shaped media where lodging is a problem; • Screen the media prior to use if lodging occurs; and • Choose a media size which can be screened or separated from the parts. To prevent burnishing: • Do not use steel burnishing shot to remove heavy burrs; and • Do not mix steel burnishing stock with abrasive media. To keep flat workpieces from sticking together: • Use small random shape media. Residue Occasionally parts may have a white residue left in recessed areas. This is generally some of the abrasive or burnishing compound which did not dissolve in water. It can be removed by a thorough ultrasonic cleaning in hot soapy water. It can be prevented by using liquid compounds in the burnishing cycle. Liquid compounds are generally not as effective as the powdered compounds, however, for burr removal or burnishing.

Table A-3 Continued. Selecting Centrifugal Barrel Finishing Conditions

Section	Discussion
	Distortion
	Large media and high "g" levels can bend precision, thin-wall components. In addition, even short exposures to centrifugal barrel operations can produce significant changes in the residual surface stresses of components. These stress changes can cause some change in flatness or straightness. The use of small media, low "g" levels and shot run times will minimize these problems. Parts 0.002 inch (50.8 μm) thick have been successfully deburred in centrifugal barrels.
	Long Flexible Burrs
	Long flexible burrs produced as a cutter passes over the back edge may not be removed from some parts. These burrs tend to double over and become U-shaped. This now-reinforced burr may be hammered flush with one side, but will not come off. These burrs, which occur frequently in the soft metals, should be removed by some other process. Beating them flush will only make them harder to remove. The use of plastic media rather than the heavier abrasives will minimize burr double-over.

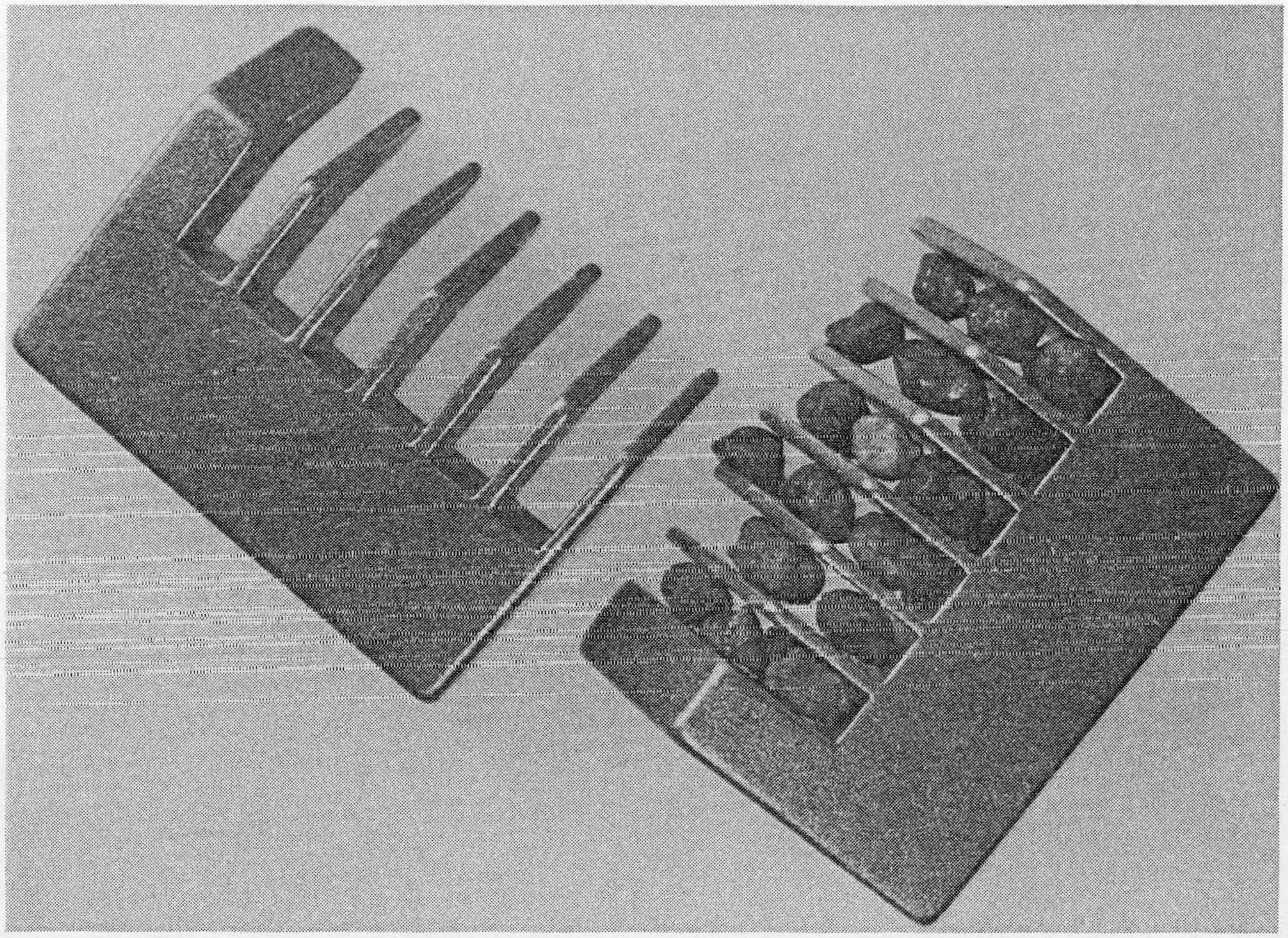


Figure A-1. Media Lodged in Slots

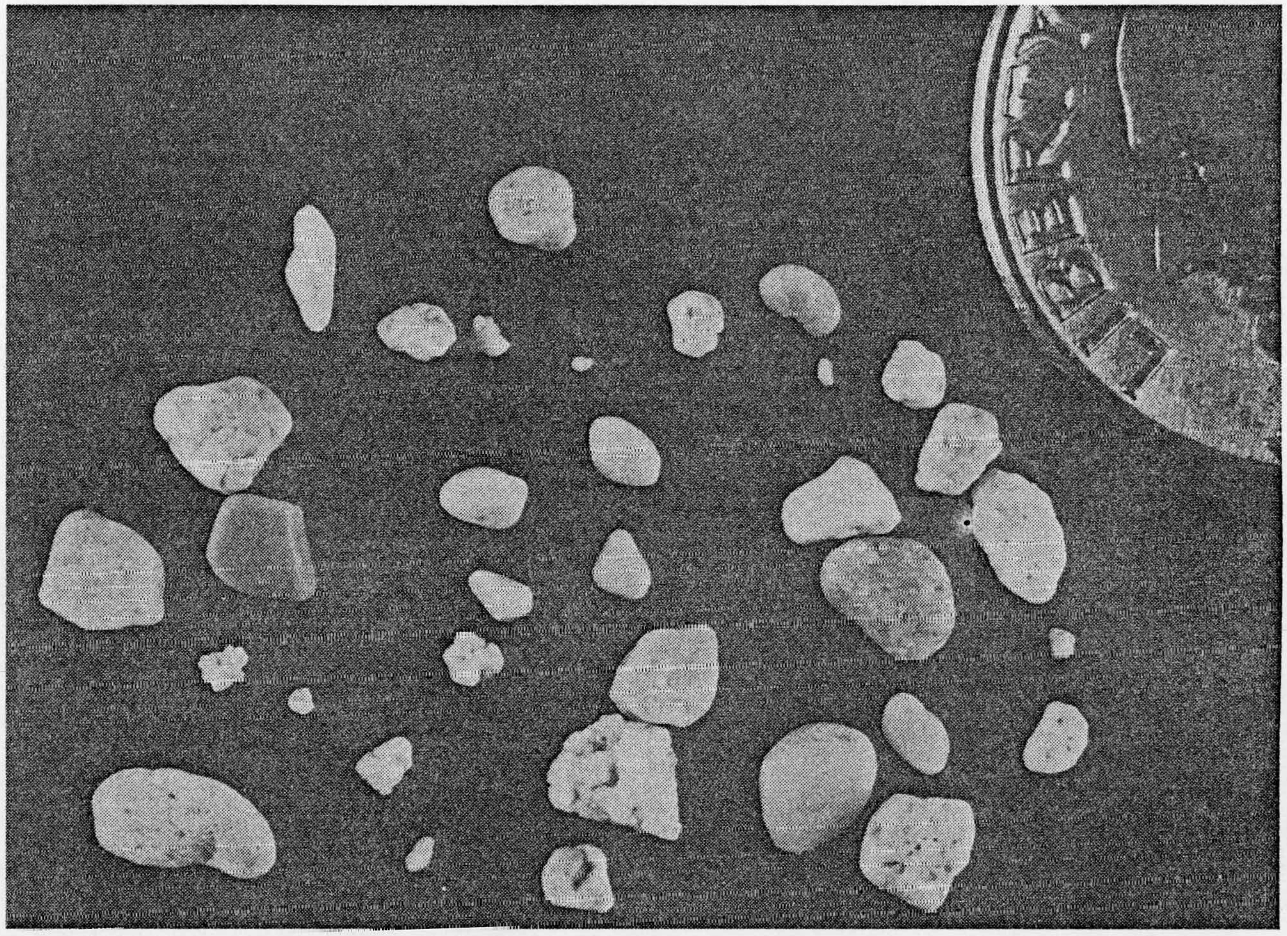


Figure A-2. Media Size Variation in Dolamite

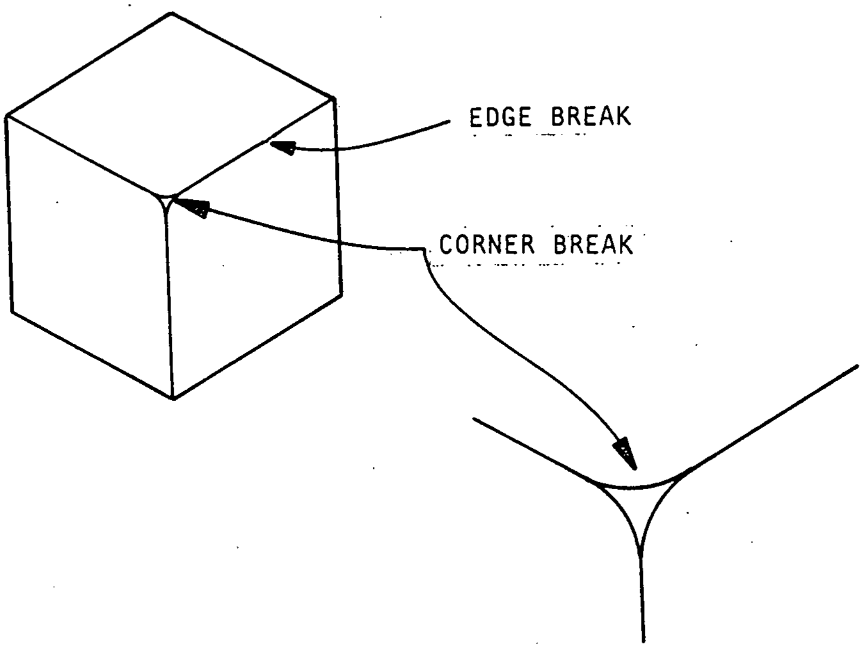
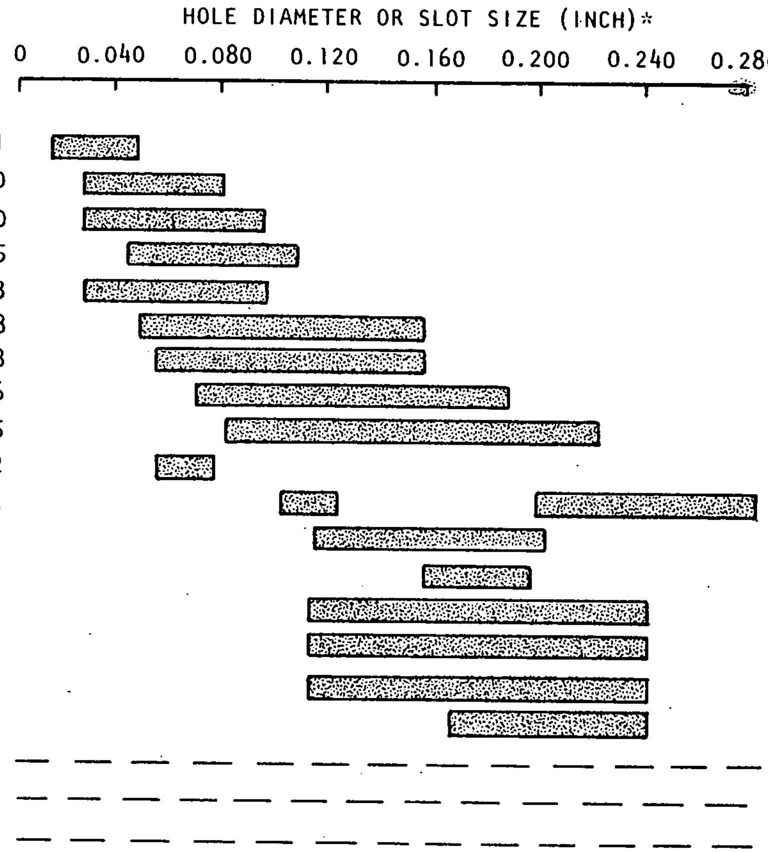


Figure A-3. Illustration of Edge and Corner Break Definitions

Table A-4. Typical Media Size Variation and Hole Sizes in Which Media Will Lodge

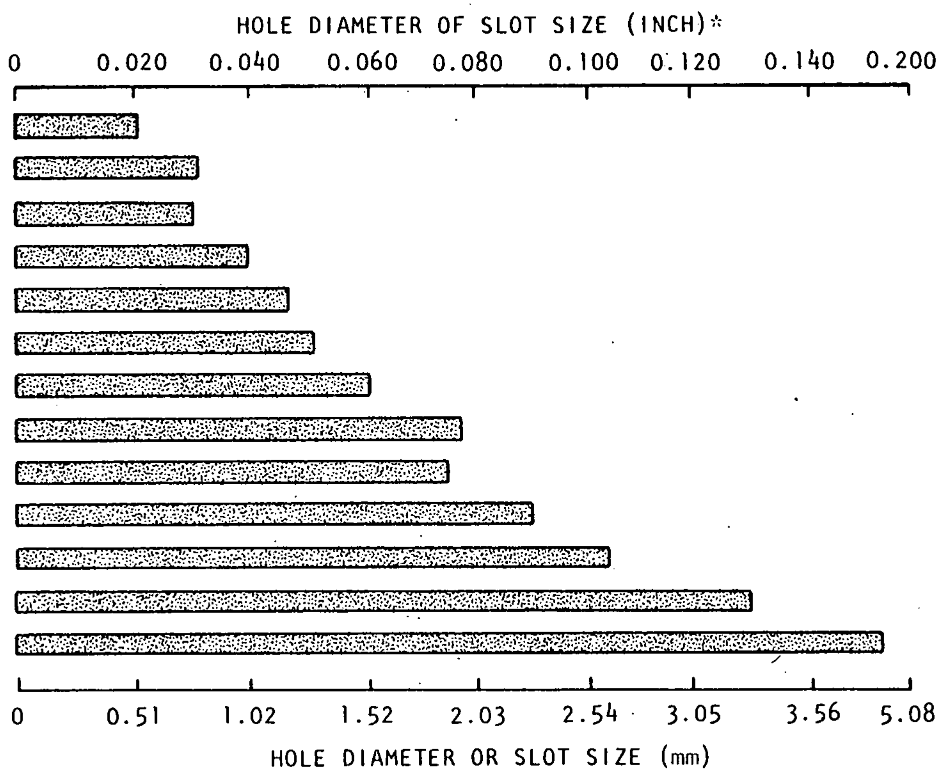
	MEDIA			HOLE DIAMETER OR SLOT SIZE (INCH)*
1	N24	Al_2O_3	10651561	
2	N16	SiC	10651520	
3	N14	Al_2O_3	10651560	
4	N12	Al_2O_3	10651575	
5	N12	DOLAMITE	10651523	
6	N8	SiC	10651268	
7	N8	Al_2O_3	10651568	
8	N7	Al_2O_3	10651566	
9	N6	Al_2O_3	10651605	
10	1/16 INCH	STEEL PINS**	10651562	
11	1/8 INCH	Al_2O_3 CYLINDERS	10651382	0.300 TO 0.350
12	3/16 INCH	Al_2O_3 TRIANGLES	10651385	
13	3/16 INCH	Al_2O_3 CYLINDERS	10651435	0.300 TO 0.410
14	1/4 INCH	PLASTIC TRIANGLES	10651625	
15	1/4 INCH	SiC TRIANGLES	10651386	
16	1/4 INCH	PLASTIC PYRAMIDS	10651556	
17	1/4 INCH	Al_2O_3 CYLINDERS	10651383	0.480 TO 0.625
18	3/8 INCH	Al_2O_3 TRIANGLES	10651380	0.250 TO 0.450
19	9/16 INCH	PLASTIC CONES	10651555	0.400 TO 0.560
20	5/8 INCH	SiC TRIANGLES	10651387	0.560 TO 0.690



*0.01 INCH = 0.254 mm. BARS INDICATE SIZE CREVICES IN WHICH MEDIA WILL LODGE, ALLOWING FOR APPROXIMATELY 20 PERCENT REDUCTION IN SIZE BECAUSE OF MEDIA WEAR.
**IF HOLE IS 0.062 INCH (1.575 mm) OR LESS DEEP, LODGED PINS CAN BE REMOVED READILY.

Table A-5. Criteria to Use to Screen Media

USE SCREEN WITH MESH NUMBER	OPENING (INCH)**	TYPE SCREEN
30	0.0203	SWECO MG***
24	0.0270	SWECO MG
20	0.0340	SWECO MG
18	0.0349	ANSI
16	0.0445	SWECO MG
14	0.0510	SWECO MG
12	0.0613	SWECO MG
10	0.0787	ANSI
10	0.0742	SWECO MG
8	0.0937	ANSI
7	0.108	SWECO MG
6	0.132	ANSI
4	0.187	ANSI
3	0.280	SWECO MG
2	0.440	SWECO MG



*USE MEDIA REMAINING ON SCREEN
**0.01 INCH = 0.254 mm
***MARKET GRADE SCREEN PRODUCED BY SWECO, LOS ANGELES, CALIFORNIA

Table A-6. Burr Sizes Typically Found on Precision Miniature Parts at Bendix

Process	Burr Size Thickness (inch)	(μm)	Height (inch)	(μm)
303 Se Stainless Steel (R_C25)				
Screw Machine	0.001	25.4	0.0015	38.1
Turning (hand feed)*	0.0045	114.3	0.0194	492.8
End Milling**	0.0035	88.9	0.0100	254.0
Side Milling** Conventional	0.0015	38.1	0.0030	76.2
"Master Cut" Cutter	0.0015	38.1	0.0005	12.7
Drilling**	0.0030	76.2	0.0065	165.1
Reaming	0.0005	12.7	0.0030	76.2
Grinding	0.0015	38.1	0.0020	50.8
Ballizing	0.0010	25.4	0.0070	177.8
17-4 PH (H900) Stainless Steel (R_C42)				
Screw Machine	0.0010	25.4	0.0015	38.1
Turning (hand feed)	0.0017	43.2	0.0018	45.7
End Milling	0.0020	50.8	0.0100	254.0
"Master Cut" Cutter	0.0005	12.7	0.0002	5.1
Grinding	0.0015	38.1	0.0020	50.8
6061-T6 Aluminum (R_B90)				
End Milling	0.0030	76.2	0.0060	152.4
Drilling	0.0030	76.2	0.0050	127.0
Reaming	0.0005	12.7	0.0030	76.2
1018 Steel (R_C20)				
End Milling	0.0035	88.9	0.0080	203.2
Drilling	0.0030	76.2	0.0055	139.7
Grinding	0.0040	101.6	0.0020	50.8

*If lathe operators exercise good machining practice they will remove the majority of this burr, by wiping sandpaper or similar abrasives over edges before the part is removed from the lathe. Data for screw machines is an estimate based on estimates from production experience. All other data is based on over 20,000 measurements.

**At the end of a cut a chip typically rolls out of the path of the cutter and produces a long roll-over burr. This burr is not included in the values shown. In the case of milling up to eight different burrs are produced with a single cut--the values shown are reasonable worst case values.

Table A-7. Conditions Which Should Result in Complete Burr Removal While Maintaining an Initial Surface Finish of 32 Microinches (0.813 μm), Stainless Steel Cube, 0.125 Inch (3.175 mm) on a Side

Maximum Allowable Edge Radius (Inch) (μm)	Allowable Thickness or Diametral Loss* (Inch) (μm)			
	0.00005 (1.27)	0.0001 (2.54)	0.0005 (12.7)	0.001 (25.4)
Burr 0.0001 Inch Thick by Any Height				
0.002 (50.8)	(3,10) (5,20)	(3,20) (5,20)	(5,40) (3,20)	(3,20) (3,40)
0.005 (127.0)	(3,10) (5,20)	(3,20) (5,20)	(3,40) (5,40)	(12,30) (3,40)
0.010 (254.0)	(3,10) (5,20)	(3,20) (5,20)	(12,30) (7,30)	Any
Burr 0.0005 Inch Thick by 0.0005 Inch High				
0.002	(3,10) (5,20)	(3,10) (5,20)	(5,40) (3,20)	(3,20) (5,40)
0.005	(3,10) (5,20)	(3,10) (5,20)	(3,40) (5,40)	(12,30) (3,40)
0.010	(3,10) (5,20)	(3,10) (5,20)	(12,30) (7,30)	Any but Media 1
Burr 0.0015 Inch (38.1 μm) Thick by 0.0015 Inch High				
0.002	(3,10) (5,20)	(3,20) (5,20)	(3,20) (5,40)	(3,20) (5,40)
0.005	(3,10) (5,20)	(3,20) (5,20)	(3,40) (5,40)	(12,30) (3,40)
0.010	(3,10) (5,20)	(3,20) (5,20)	(12,30) (3,40)	(12,40) (7,40)
Burr 0.003 Inch (76.2 μm) Thick by 0.003 Inch High				
0.002	Cannot be Met	Cannot be Met	(3,20) (5,40)	(3,20) (5,40)
0.005	(3,10) (5,20)	(3,20) (5,20)	(3,40) (5,40)	(12,30) (3,40)
0.010	(3,10) (5,20)	(3,20) (5,20)	(12,30) (3,40)	(12,40) (7,40)

Table A-7 Continued. Conditions Which Should Result in Complete Burr Removal While Maintaining An Initial Surface Finish of 32 Microinches (0.813 μm), Stainless Steel Cube, 0.125 Inch (3.175 mm) on a Side

Maximum Allowable Edge Radius (Inch) (μm)	Allowable Thickness or Diametral Loss* (Inch) (μm)			
	0.00005 (1.27)	0.0001 (2.54)	0.0005 (12.7)	0.001 (25.4)
Burr 0.005 Inch (127.0 μm) Thick by 0.005 Inch High				
0.002	Cannot be Met	Cannot be Met	(12,15) (3,30)	(12,15) (3,30)
0.005	Cannot be Met	Cannot be Met	(12,20) (3,40)	(12,20) (7,30)
0.010	Cannot be Met	Cannot be Met	(12,30) (7,40)	(12,40) (7,40)

*Values given are media numbers from Table A-4 and run time in minutes. All are at 15 g's. The most aggressive conbinations which will meet the indicated conditions are listed, because they will help assure complete burr removal and in some cases, better surface finishes. "Any" indicates almost any combination will produce the desired result.

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