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INFLUENCE OF SPECIMEN DIFFERENCES ON THE NOTCH-SENSITIVITY ACCEPTANCE TEST FOR FORGINGS OF V-57 ALLOY

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SUMMARY

This research was initiated to learn whether widely-different notched-specimen acceptance-test results for V-57 forgings truly reflect material differences or whether they result from differences in notch preparation and geometry.

Rupture properties at 1300°F were compared for three sets of notched specimens from outside sources and one set made at the University of Michigan -- all made under General Electric Specification C50T58-S4 from blanks taken from a single forging. Other specimens made at the University provided data on the influence of stress-concentration factor (K_t) and absolute size of notched specimens on the rupture life of the forging studied.

Specimens from all sources and with various K_t's from 1.8 to about 5.8 showed consistent notch weakening for a range of nominal stresses. The poor rupture strength of this particular forging thus seems to be real and not the result of peculiarities of particular specimens.

For all sets of specimens tested, the nominal stress of 62,000 psi called for in the Specification test produced shorter rupture time than did tests at either higher or lower stress levels. Contrary to expectations, the method of finishing the notch (grinding, lathe turning, or form lapping) and variation in K_t between 3.45 and 4.3 had less apparent influence on rupture times than did the absolute specimen size. The limited data showed the shortest rupture lives to occur for a diameter at the notch of d = 0.250 inch, and the longest lives for d = 0.125 inch, with intermediate results for d = 0.179 and d = 0.350 inch.

Rupture strength appeared to fall continuously with increasing K_t's out to about 3 or 4 and then increase slightly to K_t near 5.8. These observations suggest that the particular notch chosen for Specification C50T58-S4 approximates the most severe condition possible and, further, that small variations in the actual K_t from specimen to specimen should have relatively little effect on acceptance-test results.

Since these results were obtained for a forging with rupture properties that are not typical of the alloy, care must be exercised in applying the results to V-57 with more-normal properties.

INFLUENCE OF SPECIMEN DIFFERENCES ON THE NOTCH-SENSITIVITY TEST

In common with other specifications for jet-engine parts to operate at elevated temperatures, General Electric Specification C50T58-S4 requires a test for notch sensitivity in forged parts of V-57 alloy. This particular specification calls for comparative tests at 1300°F and 62,000 psi nominal stress of a smooth (unnotched) and a notched specimen with theoretical stress-concentration factor (K_t) of 3.5 to 4.0. Tests may be discontinued at 70 hours if fracture does not occur earlier. For a material to qualify, both the smooth and notched specimens must last at least 20 hours and the notched specimen must not fracture earlier than the unnotched specimen.

In a number of instances, tests on specimens cut from the test rims of some of the V-57 forgings from a producer were being discontinued after 70 hours, but specimens from other forgings from the same source failed to meet the 20-hour minimum rupture time. The present research was initiated to learn whether the widely-different acceptance-test results were a true reflection of the properties of the individual forgings or whether they result from differences in notch preparation and geometry.

Specification C50T58-S4 permits any specimen diameter up to 0.252 inches and different machine shops may employ different methods to cut the notch, to get it to final dimensions and to check dimensional accuracy. In this study, four sets of notched specimens, all made from blanks cut from the same forged disk, were to be compared in the University of Michigan laboratories under uniform test procedures, so as to minimize material and testing variables. Notch dimensions and the resulting K_t factor for all specimens were to be determined at the University by the same engineer using a single procedure, in order to reduce discrepancies from variable measuring techniques.

Three of the sets of notched specimens originated with outside sources who had experience in making V-57 specimens under the General Electric Specification, while the fourth set was prepared at the University by a hand-lapping procedure developed in an earlier research (Ref. 1) to minimize geometry variations and residual machining stresses near the root of a notch.

At least the following variables were present in the four lots of specimens obtained for study:

1) Notches finished by grinding; lathe turning; or lapping.
2) Two sources ("A" and "B") for specimens of the same size, with notches finished by grinding.
3) Stress-concentration factors ranging from 3.45 to 4.3.
4) Diameter at the notch of 0.125, 0.179, or 0.250 inch.

A common standard of comparison for data obtained with these notched specimens was provided by a curve of stress versus rupture life determined for unnotched specimens prepared at the University from other blanks from the same forged disk of V-57 alloy as was used for the notched bars.

A separate study of rupture time as a function of stress-concentration factor was specified to learn whether the particular notch used in the acceptance test was a good choice from the standpoints of sensitivity to expected variations in specimen notch geometry and of interpretation in terms of probable performance in an engine part. In addition to results for K_t of 1.0 (unnotched) and of 3.5, data were obtained for K_t's of 1.8, 2.5 and about 5.8, all with specimens made at the University with a common diameter at the notch of 0.250 inch.

Further study of specimen size as an isolated variable, or of possible strain damage in V-57 alloy when metal near the notch strains plastically during load application, was not anticipated in the original work statement. However, a limited number of survey tests in these areas were included after unexpected trends appeared in the data from the planned research program.

EXPERIMENTAL MATERIAL AND PROCEDURES

All specimens for this research were machined from specimen blanks (each approximately 0.5 in. x 0.5 in. x 3.5 in. long) sampled from a single forged disk of V-57 alloy. Technical representatives of the Structural Materials Unit, General Electric Flight Propulsion Division, identified the particular forging as serial number D-862, W-G9859, made from Carpenter Heat K-48666. They further reported the forging to be cut up according to the scheme of Figure 1 and specimen blanks to be grouped into lots assigned as follows for machining:

Machining Source	Nominal K_t	Specimen-Blank Designation
A	3.5	A4, B8, C5, C12, D8
B	3.5	A8, B5, B12, C4, D5
C	3.5	A5, A12, B4, C8, D12
U of M	3.5	A11, B3, C3, D4, D11
U of M	1.0 (Unnotched)	A1, A13, B1, B13, C1, C13, D1, D13
U of M	1.8	A2, B6, C7, D2, D10
U of M	2.5	A6, B7, C2, C10, D6
U of M	5.8	A10, B2, B10, C6, D7

Unassigned blanks were later made available for supplementary experiments.

Independent chemical analyses for Heat K-48666 were reported by the producer and by the company doing the forging. Note may be taken of the relatively-high boron content:

Element	Composition, Weight Per Cent Analysis by Producer	Analysis by Forger
C	0.044	0.058
Mn	0.17	0.15
Si	0.22	0.20
P	0.011	0.012
S	0.004	0.010
Cr	15.07	14.3
Ni	26.21	25.9
Mo	1.15	1.12
Ti	3.09	3.10
Al	0.16	0.12
Cu	0.10	
V	0.40	0.34
B	0.024	0.016
Fe	Bal.	

The forging practice and heat treatment (performed by the forging source) were reported to be as follows:

Upset and preform:	1900°F
Block and finish:	1950°F

Solution treat:	1900°F, 2 hrs., oil quench
Stabilize:	1475°F, 4 hrs., air cool
Age:	1350°F, 16 hrs., air cool.

The forger also reported the following properties for the test ring from the forging studied in this research:

0.02% Offset Y.S.	0.2% Offset Y.S.	Ult. T.S.	Elong.	R.A.	Grain Size
83,600 psi	116,200 psi	174,000 psi	14.0%	16.8%	4, 3

Routine orders, processed through regular General Electric Company channels, arranged to have specimens made at the three sources outside the University, in an effort to have dimensions and preparation methods follow usual practice at each particular source. A personal communication from W. H. Couts, Jr., of the Structural Materials Unit, gave the following details on notch-preparation procedures at these sources of specimens:

Source A: The notch is ground with an A150179BH wheel at 10,436 surface feet per minute, using a slow hand feed. The wheel is re-dressed after notches have been ground in two specimens.

Source B: A 2A120-S7-B2 wheel is used to grind the notch at a wheel surface speed in the range of 4500 to 6000 feet per minute, while the surface of the piece rotates at about 20 feet per minute. Lubrication is with undiluted Stuart "Thredcut No. 99".

Source C: The notch is cut at a lathe speed of 600 rpm, using a carbide tool with slow hand feed.

Notch preparation at the University of Michigan follows the steps illustrated in Figure 2. The first step seeks to produce a flat-bottom "V" groove of 60° included angle between sides, and with the flat having a width equal to $\sqrt{3}$ times the final desired notch root radius of curvature, r. The diameter of the specimen between flats is made equal to $r+d$, where d is the desired diameter at the finished notch. (Usually, a flat-bottom groove is rough ground to about 0.020 inch oversize with one wheel and a second freshly-dressed wheel finishes the flat to close dimensions.)

The second step in the sequence involves grinding a "nick" around the specimen along the center line of the flat just completed. For notches which are to have a root radius of 0.010 inch or greater, the wheel used in this operation is usually dressed to convenient small radius of, say, 0.003 inch; but for smaller values of r the wheel is dressed to a point.

For both grinding steps, current practice employs a speed of 3500 rpm on the Carborundum Company "Aloxite" wheel, grade A80-V2-BT and a headstock speed of 500 rpm. Flood cooling with Tidewater "Afton 8" at full strength and a slow hand feed are other features.

Hand lapping while the specimen is rotated in a lathe brings the notch to final size in a third step of the University practice. A variety of wire materials and sizes has been successfully used, but spring-bronze wire with a diameter of the order of 0.002-0.005 inch smaller than 2r is recommended. With this size wire, Clover Grease-Mixed Compound, Grade B (240 grit) is used just as it comes from the container for initial coarse lapping. If the size difference between the wire and the intended notch is less than 0.002 inch, a finer compound (Grade A or 1-A) must be used for the first part of the lapping process. A rotation speed of 190 rpm is usual for the coarse lapping with any of the above grades of compound. In use, the length of wire is wrapped around the specimen for 180° and is stroked about six inches. The wire may need to be replaced two or three times during the lapping of one notch.

After the notch approaches the aim dimensions, higher speeds and fine compounds are used, finishing with Grade 3A (500 grit). The final lapping is always done with a new piece of wire at a rather light tension of the order of 1-2 pounds.

By this lapping procedure, very accurate notch dimensions can be obtained repeatedly by an experienced mechanic, but only if the lapping is interrupted frequently to check progress. The notch is carefully cleaned with alcohol to remove all lapping compound before its current geometry is examined on a commercial 50x optical comparator.

Although the notch-lapping process was originally introduced at the University to reduce the level of residual machining stresses, its potentialities for improving reproducibility in notch dimensions was apparent -- provided the machinist had a quick but accurate way to measure the actual root radius present. A series of graded fine-line circles drawn on a piece of tracing cloth or other transparent medium permitted rapid rough comparison against the enlarged shadow projected on the ground glass of the optical comparator, but precision and reproducibility among operators were unsatisfactory for the final measurement.

The provision in most optical comparators for moving the specimen by precisely-known amounts in directions parallel to and normal to the specimen axis permits accurate measurement of the notch-root radius, when the notch root is the true arc of a circle with radius r and centered on the bisector of a 60° included angle between the sides of the notch. If these conditions of geometry are met, the circular arc of the notch root becomes tangent to the sides of the notch at a radial distance r/2 out from the bottom of the notch, and the length of the chord between these two points of tangency is exactly $\sqrt{3}$ r.

Knowing the approximate root radius, the machinist locates the base of the notch shadow at the intersection of cross lines ruled on the ground glass plate of the comparator. He then uses the transverse micrometer calipers to move the specimen a distance equal to half the believed root radius, so that the longitudinal cross line on the ground glass marks a chord across the root of the notch. With the longitudinal micrometer calipers, he measures the length of this chord. If the measured distance is greater than or less than $\sqrt{3}$ times the first value of r tried, the procedure is repeated with a better value for r/2 by which to move the specimen. A simple table listing values of $\sqrt{3}$ r for appropriate steps of r makes the operation quite fast.

By this method, different machinists consistently agreed on measured values for notch root radius within about ± 0.0002 inch. Moreover, an engineer having no prior experience with the method obtained the same precision of agreement in independent measurements made after having had the method outlined to him in a few minutes time.

Besides the notch root radius, r , the diameter d at the notch root, and the diameter, D , of the specimen shank were measured and the theoretical stress concentration was read from the appropriate curves of Ref. 2, based on the well-known mathematical analyses of Neuber (Ref. 3).

Rupture tests for both unnotched and notched specimens followed standard procedures which meet appropriate Recommended Practices of the ASTM. Loads were applied by dead weight acting through a simple lever. Specimens instrumented with Chromel-Alumel thermocouples were placed into individual resistance furnaces at room temperature. Test temperature of 1300°F was approached in about three hours, but loading took place only after the laboratory technician had assured himself that the specimen temperature had become stabilized and was uniform along the gauge section in the case of unnotched specimens. Rupture time was automatically recorded to the nearest 0.1 hour if failure took place when the laboratory was unattended.

RESULTS

Test results of the investigation pertained to the following factors:

1. Comparative stress-rupture time characteristics at 1300°F for notched specimens made by four different organizations to meet the requirements of Specification C50T58-S4 for acceptance rupture tests of V-57 alloy.

2. Comparison of notched-specimen rupture times with those for unnotched specimens at 1300°F.

3. Influence of stress-concentration factors of 1.8, 2.5, 3.5, and about 5.8 on stress-rupture time properties at 1300°F.

4. A very limited investigation of the influence of specimen size on results of tests on notched specimens at 1300°F.

In addition, yield strength was determined at 1300°F for two specimens under loading conditions similar to those for the rupture tests. These same two specimens were used to survey the influence of initial short-time plastic straining on subsequent rupture life.

Influence of Source of Specimen Preparation

Four sets of specimens, three from outside sources and one made at the University, investigated effects of variable preparation of specimens made at different places for acceptance rupture tests under Specification C50T58-S4. The results, given in Table 1, were combined with data from tests on specimen-size effect for graphical presentation as stress-rupture time curves. The overall trends of the combined data were believed more meaningful than would be the indications from the limited study on specimen source alone.

The combined data (Figure 3) indicate the following:

1. The specimens made at the University with 0.250 inch diameter at the notch had distinctly shorter rupture times than did specimens supplied by sources A, B, or C.

2. There was no consistent difference in the results at 61,000 - 63,000 psi for rupture tests on specimens from sources A, B, and C. For lower stresses, specimens from source C appeared to have shorter rupture times than those from the other two sources. This latter observation is based on extremely limited data and appears to be related to the characteristics of specimens with 0.125 inch diameter at the notch as compared to larger specimens.

3. The overall data of Figure 3 (supported by test results to be presented later for specimens with other stress-concentration factors) indicate shorter rupture times at an intermediate nominal stress of about 62,000 psi than for either slightly higher or slightly lower nominal stress. The result was a tendency for the stress-rupture time curves to approach the form of a flattened "Z". Other data obtained at the University support this effect as being real. Tests for General Electric on Cast DCM alloy at 1200°F (Ref. 4) exhibited this type of plot. It is believed that more extensive testing of specimens from the four sources would prove this behavior to be a real characteristic of the material.

In this part of the investigation, the following variables were present:

(a) Specimen size

(b) Method of preparing the notch

(c) A variation in stress-concentration factor, K_t, between 3.45 and 4.3.

In prior extensive research at the University, the effect of specimen size, particularly for specimens as small as were supplied by sources A and B, had not been investigated. Considerable evidence had been found to indicate that methods of preparing notches could influence the results of tests with some materials to a marked extent. The influence of K_t had been studied extensively and found to be a particularly large effect on rupture life in the lower ranges of K_t. In view of the possibility that specimen size was a factor in the present results, a very limited study of size effect was undertaken before attempting to draw conclusions.

Effect of Specimen Size

Three specimens each with minimum (notch) diameters of 0.125 inch and of 0.350 inch were prepared at the University with a K_t of about 3.5 to compare with the data for the corresponding 0.250 inch-specimens initially tested. The results (Table 2 and Fig. 4) indicate the following:

1. Specimens with 0.125- or 0.350-inch diameter at the notch had longer rupture times than were obtained for the notched specimens with 0.250-inch notch diameter.

2. Both the 0.250 and 0.350-inch specimens had stress-rupture time curves similar to those for the 0.179-inch specimens from source C. This was particularly true for tests below 62,000 psi.

3. The 0.125-inch specimens gave results similar to those for the 0.125-inch specimens from sources A and B.

The extremely limited data suggest, therefore, that a specimen-size effect was overriding any effects from method of preparing the notches or from the minor variations in K_t present in the specimens. It should be recognized, however, that this change in rupture time with specimen size, and especially the apparent lower rupture times for 0.250-notch diameter than for either smaller or larger size, was not well established. The curve for the 0.179-inch specimens from source C was possibly shifted to longer times as a result of the high residual compressive stresses induced by this method of machining the notch. On the other hand, the disturbed metal at the base of the notch from turning could have adversely affected the strength.

The apparent agreement between the lapped notches made at the University and the ground notches made by sources A and B in 0.125-inch specimens could reflect relatively stress-free notches in both cases. This would require unusual control of grinding.

It is to be emphasized that within these limitations the data generally indicate a predominant effect of specimen size.

Notch Sensitivity of Experimental Material

Data for unnotched specimens (Table 3) were obtained for comparison with the tests on notched specimens. Inspection of Figure 3 shows that none of the variables investigated resulted in tests on notched specimens with a longer rupture time than smooth specimens. The particular disk tested, therefore, is definitely notch sensitive at 1300°F over the range of nominal stresses investigated for K_t values of 3 to 4.

The data do suggest that tests at stresses below about 60,000 psi would probably have shown notch strengthening for 0.125-inch specimens. The larger specimens, however, gave no indication that this would have occurred.

Inspection of the data, moreover, indicates that the acceptance-test conditions of 62,000 psi nominal stress resulted in shorter rupture times than either somewhat higher or somewhat lower stresses would give. For this reason, the stress selected was the most severe that could have been imposed on the material for the particular notch used.

It should be noted that the data for smooth specimens show some scatter around the stress-rupture time curve. This is normal for tests on specimens cut from a forging of the size investigated. It is, however, most important to recognize that the same variations must inevitably have been present in the tests on notched specimens. It is for this reason that the data have been analyzed from the general trend basis rather than for specific test results. Even then, the possibility of false trends exists due to data scatter. The specimens were randomized to minimize this effect but there is no real proof that this was completely successful.

It should be noted that the rupture strength of the smooth specimens was on the high side of the range for the alloy. Moreover, the elongation and reduction of area values were abnormally low. Therefore, even the test results on unnotched specimens indicated peculiar characteristics for the material tested.

Influence of Stress-Concentration Factor

Specimens having a diameter of 0.250 inch were made at the University with K_t values of 1.8, 2.5, and about 5.8 to supplement the data previously given for a K_t of 3.5. The test results (Table 3 and Figs. 5 and 6) indicate:

1. A minimum rupture time for a K_t near 3.5 for stresses down to about 62,000 psi. The rupture time decreased quite rapidly with increasing K_t to about 3.5 and then apparently increased again for stresses above 60,000 psi.

2. None of the notched specimens exhibited definite notch strengthening. This is most unusual. In most cases, the rupture time is first increased from that of smooth specimens as the K_t is increased up to values of 1.8 to 2.0 or slightly more and then it falls off with a further increase. Lack of this characteristic is the most striking indication of abnormal notch effects during rupture tests for the material investigated.

3. Most materials exhibit the leveling off or actual increase in rupture time for the sharper notches that was observed in this investigation. The material studied was, therefore, normal in this respect.

4. This response to K_t suggests that rupture times are not particularly sensitive to K_t for the acceptance test specimen.

5. All of the stress-rupture time curves exhibited the tendency for a "Z" type curve. It should be recognized, however, that the data for a K_t of 5.8 mainly show about the same rupture time for all tests over the range considered. For this reason, if the

results shown in Figure 6 had been for stresses below 60,000 psi, the curves would apparently not have exhibited a minimum, but rather a more or less regular decrease in rupture time with K_t to 5.8.

Strain Damage

Two unnotched specimens at 1300°F were loaded in the rupture units until yielding occurred. The stresses were then reduced to lower values and the load maintained until rupture occurred. The results follow:

Maximum Stress (psi)	Strain at Maximum Stress (%)	Rupture Stress (psi)	Rupture Time (hrs)	Elongation (%)	Red. of Area(%)	Normal Rupture Time(hr)
117,090	a)2.25	71,550	7.1	4.	4.5	26.5
121,500	1.15	65,750	37.9	2.	2.5	63.

a) The high stress was held for 10-15 seconds before the overload was removed.

In both cases, the rapid strain during loading was followed by reduced subsequent rupture time. This may be important in that it indicates that the material being tested is subject to a loss in life as a result of the yielding that necessarily takes place at the base of a notch even of moderate K_t during loading to the acceptance-test nominal stress.

This observed loss in life as a result of the yielding could result from the rupture life being used up very rapidly at the high stresses which existed even though they were present for only a short time. The yielding, of course, reduces the effective stress.

Alternately, the material could receive damage to subsequent rupture resistance as a result of plastic yielding.

Yield Strength

Two unnotched specimens loaded at 1300°F under the loading conditions of a rupture test provided data (Fig. 7) for the following offset yield strengths, psi:

0.02% Offset	0.2% Offset
94,500	109,600
91,000	110,200

Unreported Data

Creep data were taken for all the tests on unnotched specimens but are not included in this report since they are not pertinent to the objectives of the investigation. The reduction of area of the notched specimens were also not reported. Both types of data could, however, be furnished upon request.

Measurement of Notches

Table 1 lists the values for notch root radius (r) and specimen diameter (d) at the notch, both as reported by the specimen source and as measured at the University of Michigan. Agreement in d values was excellent, within 0.0002 inch in most instances. But, the 0.004 inch value for r reported by sources "A" and "B" differed from the measurement made at the University by as much as ±0.0008 inch. These results may be interpreted to say that the methods used to measure r were less precise than those employed to measure d.

DISCUSSION

The objective of the investigation was to determine if there were variables in the acceptance test specimen which could change the evaluation of notch sensitivity under the test conditions. Before considering the significance of the results from this viewpoint, it is important to recognize that the forging tested had abnormal notch sensitivity. Because the results could be quite different for the usual notch-ductile V-57 material, no general conclusions extending the results of this investigation to such materials should be made without further verification.

It should be recognized that the material tested exhibited notch sensitivity over a rather wide range of conditions. For this reason, it would be rather easy to lose sight of the fact that if the material had exhibited intermediate notch sensitivity, many of the variables studied would have shifted the test results between notch strengthening and weakening. Therefore, if intermediate-sensitivity materials exhibited the same response to the variables as those found in this investigation for highly notch-sensitive material, the conclusions might have been quite different.

For the material studied, the stress of 62,000 psi was about the most severe test for notch sensitivity which could have been made. For the stress-concentration factor of approximately 3.5 required for the test, rupture time was low in comparison to tests at slightly higher or lower stresses. Inspection of Figure 3 suggests that little or no notch weakening would have been found for 0.125-inch specimens if stresses of 62,500 or 60,000 psi had been used. It should be recognized that the usual test procedure allows a stress variation of ± 620 psi (1%). Thus, tests which happened to be run with the stress on the high side might have passed.

The material tested exhibited what appeared to be a marked influence of specimen size. The results indicate that the use of 0.250-inch specimens would be a considerably-more severe test of notch sensitivity than 0.125-inch or even the 0.179-inch specimens. Specimen size appeared to be the most influencial variable of the investigation. For this reason, it would appear essential that its role in tests on notch ductile material should be examined both from the viewpoint of the acceptance test and its relation to service performance.

Due to the fact that the material tested was not particularly sensitive to stress-concentration factor, the variations in K_t between specimens from different sources seemed to have little effect. Sources A and B furnished 0.125-inch specimens which differed by about 3.5 to 4.0 in K_t. Yet, no significant difference was apparent. Thus, the finding for 0.250-inch specimens which indicated a rupture-time minimum for K_t values in this range (and which, therefore, resulted in little effect from such variations in K_t) appears to be valid for both specimen sizes. At least, slight K_t differences were not a significant factor in the results for the material tested.

The choice of a K_t of 3.5 to 4.0 for the acceptance test apparently results in the most-severe conditions of notch weakening. From this viewpoint, the acceptance test again imposes the most-severe test possible, without particular sensitivity to the precise value of K_t for any given specimen.

Two features should be recognized in the study of the influence of K_t over wide ranges which substantiated that the most severe notch weakening occurred at a K_t of about 3.5 to 4.0. The data indicate that if the testing stress was somewhat lower than 60,000 psi, the weakening effect of the notch would continue to higher K_t values. Under these conditions, the exact K_t would have considerable more influence. However, if more-normal material has a different response to K_t, the conclusion of insensitivity to K_t could be invalidated. Secondly, one may presume that if the K_t had been varied for 0.125-inch specimens over the same range, considerable areas of notch strengthening would have been encountered for the lower K_t values.

At the time the investigation was started, the method of making the notch had been expected to be quite influential. However, any effects from this source were obscured by the size effect. It is not known if this is an effect peculiar to the forging tested or if the effects of notch-preparation differences were overshadowed by other effects in small specimens. The earlier research at the University showing marked differences between lapped relatively-stress-free notches and the turned or ground notches was based on specimens 0.250 inch or larger.

The reasons for the unexpected effects encountered were not determined in this investigation. The yield characteristics did not seem to explain the peculiar short rupture times for tests at a stress of 62,000 psi and a K_t of 3.5 to 4.0. The cause for the apparent influence of specimen size is also not clear. It must be recognized, however, that several variables are operating simultaneously in different directions. The yielding redistributes stresses and reduces the stress concentration. At the same time, plastic deformation apparently damages the rupture strength of the material. Variations in specimen size alter the strain gradients. Residual stresses and disturbed metal vary with the specimen size. For instance, the lapping procedure used may not have removed all the disturbed metal at the base of the notch for 0.125-inch specimens. The influence of surface oxidation may vary with specimen size. The changing interaction of all the variables with stress and time could, therefore, lead to the apparent unusual effects. A further possibility is that a change in mechanism of fracture with nominal stress could be involved.

In all of the investigation, possible scatter in the properties of the individual specimens has been of concern, together with influence on results from normal testing-condition variations. The specimens were randomized to minimize the influence of variations between specimens, but scatter in test results could have been a greater factor than has been recognized. The findings of the investigation do seem to be sufficiently general when all data are considered to fairly well eliminate chance effects from scatter.

One of the most intriguing aspects of the investigation was the cause for the high degree of notch sensitivity exhibited by the material tested. This investigation was not concerned with this problem. In passing, however, it should be noted that for unknown reasons the material had a high level of rupture strength and relatively-low ductility in rupture tests. It is suspected that the material was quite resistant to relaxation of stress concentrations by creep. Because yielding must have been extensive in the tests on notched specimens, the importance of this factor is not clear. However, the loss in rupture strength by yielding certainly was a major factor. It is possible, or even probable, that the rather high boron content of the heat, 0.023 percent, may have been responsible for the high creep resistance and susceptibility to strain damage. This premise would, however, require further proof.

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Table 1

Comparative Rupture-Test Results at 1300°F with Notched Specimens Made to Meet the Requirements of Specification C50T58-S4

Specimen Blank Designation	a) Initial Notch Dimensions: As Stated by Machining Source r	d	As Measured at U of M r	d	D	K_t	b) Nominal Stress (psi)	Rupture Life (hr)
			1/8 in. diam. Notches Ground by Source "A"					
-	0.004	0.1244	0.0034	0.1245	0.176	4.05	65,345	16.0
-	0.004	0.1244	0.0033	0.1243	0.178	4.0	63,845	33.3
-	0.004	0.1253	0.0033	0.1252	0.178	4.0	62,425	106.9
-	0.004	0.1257	0.0035	0.1257	0.176	3.9	61,500	20.2
-	0.004	0.1248	0.0034	0.1246	0.177	4.05	61,325	27.0
-	0.0045	0.123	0.0043	0.1232	0.1768	3.55	60,000	82.4
			1/8 in. diam. Notches Ground by Source "B"					
C-4	0.004	0.1243	0.0045	0.1241	0.177	3.5	63,000	33.2
B-5	0.004	0.1246	0.0046	0.1246	0.177	3.45	62,345	21.2
D-5	0.004	0.125	0.0045	0.1253	0.177	3.5	61,000	27.4
B-12	0.004	0.125	0.0048	0.1248	0.177	3.4	60,340	127.1
			0.179 in. diam. Notches Turned by Source "C"					
B-4	-	0.1785	0.0043	0.1787	0.250	4.2	63,000	51.7
C-8	-	0.1785	0.0041	0.1787	0.250	4.3	62,165	19.0
A-5	-	0.1785	0.0043	0.1791	0.250	4.2	60,150	52.0
A-12	-	0.1785	0.0043	0.1794	0.250	4.2	58,000	67.6
D-12	-	0.1785	0.0042	0.1789	0.250	4.25	56,000	77.5
			1/4 in. diam. Notches Ground + Lapped at U of M					
-	-	-	0.0088	0.2494	0.375	3.6	65,000	11.2
-	-	-	0.0091	0.2487	0.375	3.55	63,500	4.2
-	-	-	0.0093	0.2493	0.375	3.5	62,000	9.8
-	-	-	0.0088	0.2476	0.375	3.6	60,000	19.2
-	-	-	0.0093	0.2493	0.375	3.5	55,000	37.4

a) r = Notch root radius of curvature, inches
d = Specimen diameter at the notch, inches
D = Shank diameter of specimen, inches
K_t = Theoretical (elastic) stress concentration factor

b) $$\text{Nominal Stress} = \frac{\text{Load}}{\text{(Initial Cross Section at the Notch)}}$$

Table 2

Results at 1300°F of Rupture Tests on Three Sizes of Notched Specimens of V-57 Alloy, For Uniform Theoretical Stress Concentration Factor of 3.45 to 3.6

Specimen Blank Designation	[a] Initial Notch Dimensions r	d	D	K_t	[b] Nominal Stress (psi)	Rupture Life (hr)
	1/8 in. diam. Notches Ground + Lapped at U of M					
C-9	0.0043	0.1244	0.1775	3.55	65,000	12.3
[c]A-3	0.0043	0.1242	0.1775	3.55	63,500	17.2
[c]A-3	0.0043	0.1243	0.1775	3.55	60,000	108.3
	1/4 in. diam. Notches Ground + Lapped at U of M					
	0.0088	0.2494	0.375	3.6	65,000	11.2
	0.0091	0.2487	0.375	3.55	63,500	4.2
	0.0093	0.2493	0.375	3.5	62,000	9.8
	0.0088	0.2476	0.375	3.6	60,000	19.2
	0.0093	0.2493	0.375	3.5	55,000	37.4
	0.350 in. diam. Notches Ground + Lapped at U of M					
C-11	0.0127	0.3514	0.5005	3.5	65,000	3.0
B-11	0.0129	0.3528	0.5005	3.45	63,500	12.4
A-7	0.0130	0.3530	0.5005	3.45	60,000	31.3

a) r = Notch root radius of curvature, inches
d = Specimen diameter at the notch, inches
D = Shank diameter of specimen, inches
K_t = Theoretical (elastic) stress concentration factor

b) $$\text{Nominal Stress} = \frac{\text{Load}}{\text{(Initial Cross Section at the Notch)}}$$

c) Original specimen blank split lengthwise into two smaller blanks

Table 3

Variation with Theoretical Stress Concentration Factor (K_t) of Rupture-Test Properties at 1300°F for 0.250-Inch Diameter Specimens from a Forged Disk of V-57 Alloy

UNNOTCHED SPECIMENS (K_t = 1)

Stress (psi)	Rupture Life (hr.)	Elongation (%/ 1 inch)	Reduction of Area (%)
75,000	15.9	3.	4.
72,000	24.6	2.	2.5
70,000	34.7	2.	1.5
67,500	40.9	2.	3.
66,000	41.1	6.	8.
65,000	87.9	2.	2.
63,500	94.7	0.5	1.
62,085	153.7	1.	1.5
60,000	136.0	1.	1.
a) 71,550	7.1	4.	4.5
b) 65,750	37.9	2.	2.5

a) Prestrained 2.25% by 10-15 seconds at 117,090 psi at start of test.

b) Prestrained 1.15% by momentary overload to 121,500 psi at start of test.

NOTCHED SPECIMENS

Specimen Blank Designation	c) Initial Notch Dimensions r	d	D	K_t	d) Nominal Stress (psi)	Rupture Life (hr)
		Nominal K_t = 1.8				
C-7	0.0499	0.2495	0.375	1.80	68,000	43.2
B-6	0.0503	0.2497	0.375	1.80	65,000	99.5
A-2	0.0504	0.2502	0.375	1.79	62,000	99.2
D-2	0.0501	0.2503	0.375	1.80	59,000	75.9
D-10	0.0504	0.2493	0.375	1.79	57,000	94.1

Table 3 (Continued)

NOTCHED SPECIMENS

Specimen Blank Designation	c) Initial Notch Dimensions r	d	D	K_t	d) Nominal Stress (psi)	Rupture Life (hr)
			Nominal K_t = 2.5			
-	0.0209	0.2497	0.375	2.5	65,000	28.5
-	0.0208	0.2492	0.375	2.5	63,000	42.4
-	0.0207	0.2495	0.375	2.5	62,000	24.3
-	0.0204	0.2493	0.375	2.55	60,000	17.3
-	0.0201	0.2477	0.375	2.55	55,000	80.0
			Nominal K_t = 3.5			
-	0.0088	0.2494	0.375	3.6	65,000	11.2
-	0.0091	0.2487	0.375	3.55	63,500	4.2
-	0.0093	0.2493	0.375	3.5	62,000	9.8
-	0.0088	0.2476	0.375	3.6	60,000	19.2
-	0.0093	0.2493	0.375	3.5	55,000	37.4
			Nominal K_t = 5.8			
-	0.0035	0.2506	0.375	5.45	65,000	15.7
-	0.0026	0.2487	0.375	6.25	63,500	14.6
-	0.0035	0.2504	0.375	5.45	62,000	16.6
-	0.0032	0.2504	0.375	5.65	60,000	9.1
-	0.0025	0.2487	0.375	6.4	57,000	12.9

c) r = Notch root radius of curvature, inches
d = Specimen diameter at the notch, inches
D = Shank diameter of specimen, inches
K_t = Theoretical (elastic) stress concentration factor

d) Nominal stress = $\dfrac{\text{Load}}{\text{Initial cross section at the notch}}$

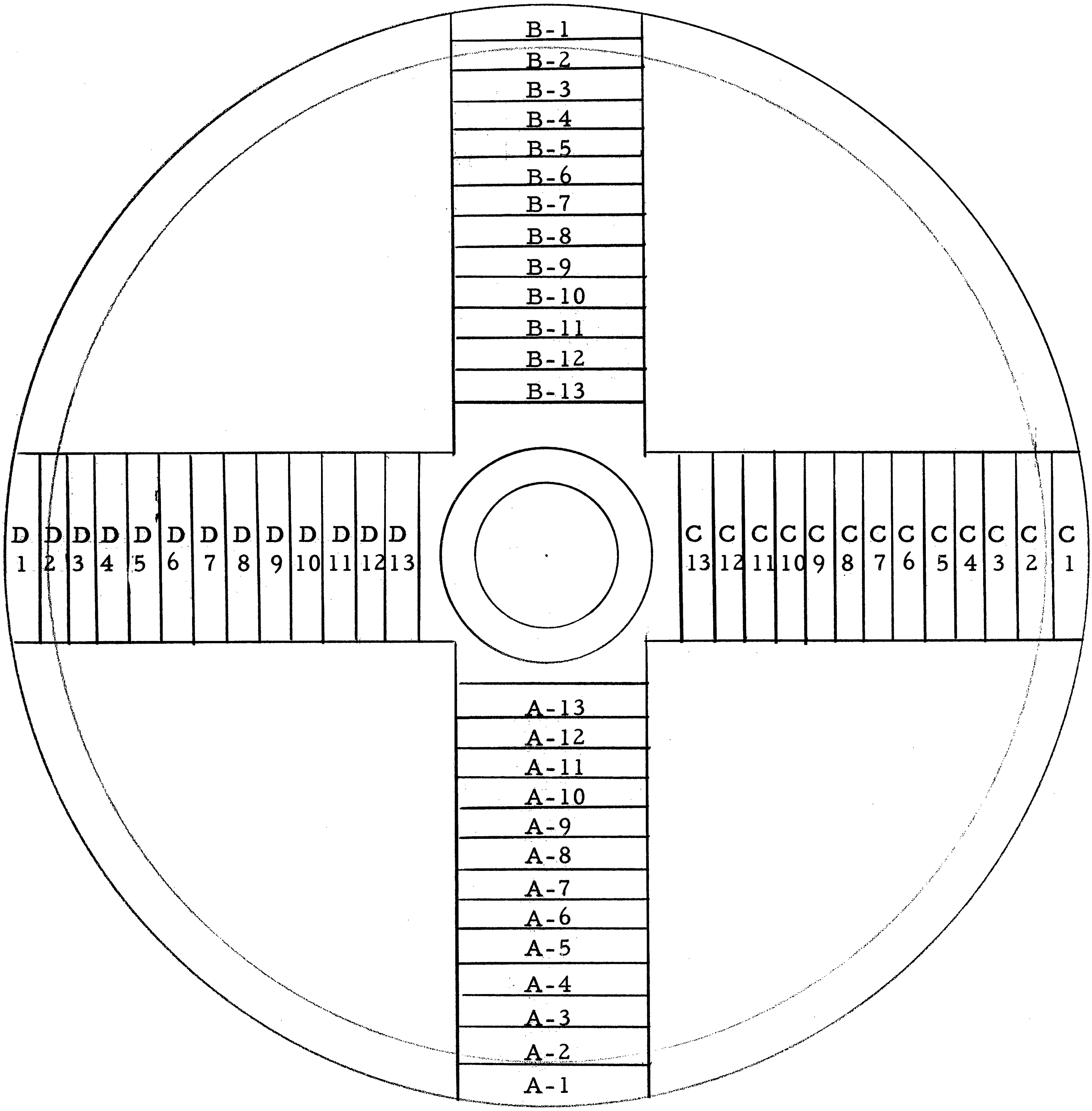

Fig. 1 - Sketch Indicating Locations in V-57 Forging Serial D-862 from which Specimen Blanks were Sampled.

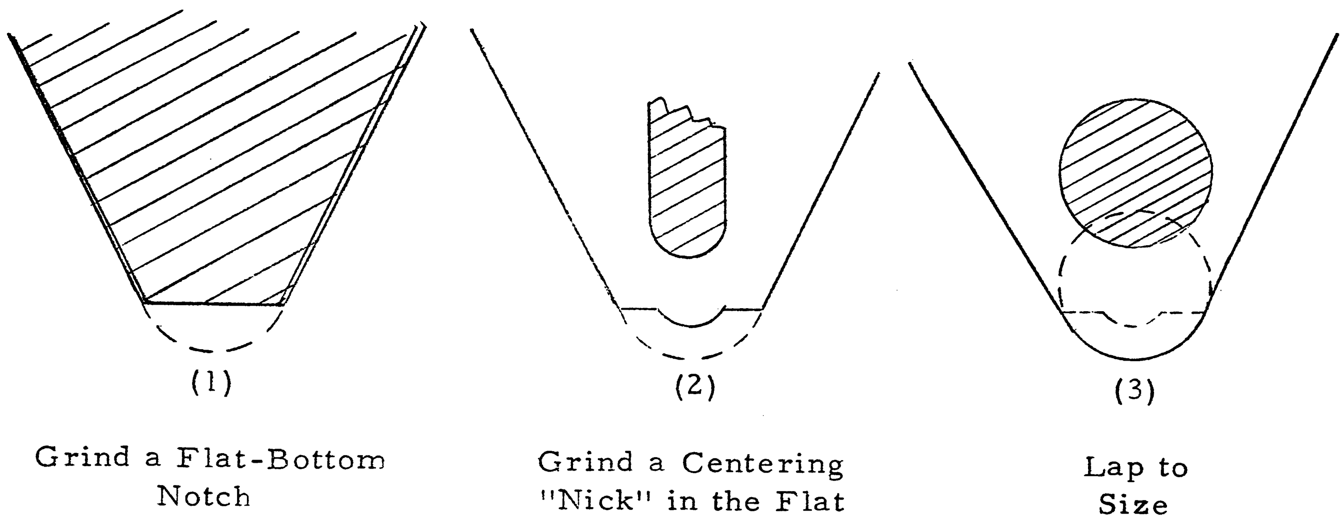

Fig. 2 - Steps Followed in Notch Preparation at the University of Michigan.