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Stability starts with the purchase specification

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ABSTRACT

Comprehensive Purchase Specification(s) must not merely define a generic type of material by chemistry and mechanical properties. It must be capable of specifying the method of material formation (i.e. rolled, cast, forged, vacuum hot pressed, etc.) it's grain size, preferred orientation, homogeneity, etc, and the method of material removal to minimize surface damage and/or work hardening.

Starting out with heavily stressed material will, in many instances, negate the possibility of fabricating components which can be subsequently processed and heat treated to eliminate the residual stresses which cause components to change dimensionally and/or creep or experience premature micro-yielding - the anisotropy of work hardening *Bauschinger Effect..*

MATERIAL AND FORM SELECTION

In order to produce parts or precision assemblies with maximum stability, one must recognize the various forms that are available and the selection of alloys to choose from. The next step may be selecting a form with the best homogeneity, or a form which will permit the subsequent processing to a condition of useable stability (minimum residual stress).

Another vexing problem is the fabricating of parts from bar or plate for prototypes, and the subsequent purchase of cast or powder compacted parts for production. Two very diverse material conditions.

A brief familiarization (See Figure 1 and 2) with the forms available from a partial list is a starting point in the ultimate selection of form, alloy, condition and subsequent processing to final state. Note that we have not touched on cost, availability or delivery time.

In order to achieve the best or optimum decision to purchase correctly, we really must know all the facts that a well prepared process and data sheet can provide.

Then we can evaluate and compare expected delivery to floor to floor costs. (The overall costs of fabrication including material, not just the basic material costs.)

An example of ordering data for a quality casting:

- Procurement specification A1000 for A-356.0 aluminum castings
- MIL specification MIL A 21180C
- Radiographic Inspection Quality Grade C
- Drawing No. D 999 Rev O
- Heat treat as per instructions
- Cut tensile test bars from casting where shown
- Mechanical properties of bars must conform to Class 1 when tested by Method 211.1 of Fed. Test Standard No. 151
- Sample plan as per MIL-STD 105 Inspection Level S-2
- Pack in accordance with MIL-STD-1188
- Mark in accordance with MIL-STD-129
- Note areas where gates, risers and chills are to be avoided.

While this does provide the foundry with a good amount of instructions to produce a casting which will meet all our basic requirements, the subsequent machining may require even more detailed instructions to avoid adding stresses to the casting which will ultimately contribute to its instability. If this requires an additional purchase order, it may not be adequate to merely state "machine to blueprint". More detailed instructions may be warranted. Figures 3 thru 6 show cross sections of parts with machining damage and removal of the damage by etching and by annealing at various temperatures.

Stringent stability requirements increase the need for materials which will not change dimensionally thru normal use. Some of these problems have been ameliorated by replacing conventional materials with newer engineered materials. It may be difficult or costly to effect this type of substitution in many instances. Innumerable inquiries requiring immediate solutions often initiate from optical or precision manufacturing personnel whenever a finished or semi-finished part shows signs of movement (instability). In a majority of these instances it is too late to institute any corrective action to remedy the situation. The final material condition is usually influenced by the prior history of its initial formation - the actual foundry or mill processing method.

We must first consider the standard or usual method, and then the less frequent, or perhaps more costly, method.

BAR

We generally purchase bar or sheet material - usually rolled to size, but in some instances the bar may be extruded. In bar, the rolled material will exhibit preferred orientation (texture) with the direction of rolling. Therefore, the longitudinal mechanical properties will vary considerably with the transverse properties. In addition to the orientation caused by rolling, the surface will be harder than the subsurface due to work hardening. The grains when viewed in cross section will be compressed. The compressed surface grains may be .005 to .010 inches thick, before the material exhibits homogeneity.

SHEET

Sheet material is produced by rolling (several passes or reductions) and in some instances cross rolled. While the cross rolled material will have transverse and longitudinal properties more closely aligned, the thru the material ("Z" direction) will be significantly different and much lower in tension.

In order to convert these highly stressed materials to more homogeneous materials may require machining and/or etching and stress relieving to remove the layer caused by rolling. This must be done to both sides of the material or their uneven stresses will cause a warpage similar to a bimetalic of two (2) materials with different coefficients of expansion.

TUBING

Hollow sections produce another set of conditions.

Tubing is produced by several methods:

- It may be rolled from sheet and welded.
- The weld may be planished and drawn over a mandrel.
- The tube may be seamless. A solid billet is pierced and then extruded thru dies.

All tubing will have a skin (compressed layer) both inside and outside. The longitudinal properties will vary considerably from the circumferential properties. Thru the thickness (radial direction) will resemble sheet material and much of the inhomogeneity experienced in sheet material will be evident in tubing.

RINGS

Rings are produced by two (2) general methods - by forging or by rolling and welding. See figure 7. Annealing these parts will greatly reduce the forging and rolling stresses but certainly not eliminate them. Machining sufficient material from all surfaces will further reduce these residual stresses.

CASTINGS

Aside from closed die forging and die casting, near net shape forming is an ongoing expanding development. Casting whether by fine sand with matched plate patterns or by investment castings, expanded polystyrene or by plaster mold, are old and reliable methods of reducing machining costs and producing parts with moderately uniform properties. However, castings have porosity and a skin effect. In order to achieve homogeneous dense parts it is necessary to consolidate the material to near theoretical density by Hot Isostatic Pressing (HIPing).

POWDERED METALLURGY

Parts made from powder may be produced by four (4) general methods:

- Die compaction and sintering
- Injection moulding and sintering
- Cold Isostatic Pressing, Sintering and HIPing
- Hot Isostatic Pressing an evacuated can or glass envelope

Die compaction of powder and injection moulding both produce a great deal of inhomogeneity (see figure 8) which can only be partially removed by annealing, and both will posses varying degrees of porosity dependent on both metallurgical and die parameters. The cold isostatic and hot isostatic formed parts will provide the best homogeneity but at much higher costs due top the number of operations required to produce these parts.

It should be apparent at this point to acknowledge the manifold options available in selecting the basic material(s) which has the potential of achieving the desired stability, and still able to capitalize on the benefits of obtaining preformed or near net shape materials.

The lure of apparent cost reduction especially on parts to be produced in large quantities can often block logic and obfuscate the designers real intent. When a load of incorrect parts arrive at the machine shop on schedule it is usually too late to reorder replacement material, and the attempted salvage plans may be more disastrous in attempting to circumvent the problem with various fixes, which will either be partial fixes or unsuccessful attempts to utilize material procured with incomplete or incorrect specifications.

SPECIFICATIONS

Do they measure up? How can I get by without a special, full blown, specification? Some specifications can create more problems than they resolve. This condition may arise from several causes.

1. The specification may be designed too closely to a manufacturers specification, which may be too broad to satisfy any of the critical stability requirements.

2. The specification may be made to follow a military or AMS specification which again may not address certain significant physical properties, in its attempt to remain broad in scope.

3. The specification may be prepared by person or persons unfamiliar with all the requirements or incapable of converting these needs to clear, concise, unambiguous instructions.

We have all read specifications which ran the gamut from worthless to excellent. I personally try to use ASTM specifications where applicable. Most suppliers/manufacturers will certify conformance to ASTM specifications but few will have actual test data to accompany the parts, and even fewer will sign up to the many tests listed as optional due to the involved attention to detail essential in fabricating test specimens, running the tests, and completing the documentation, not to mention the time required or increased cost associated.

Now is there a short cut to all this? I doubt it. I do believe that many of the problems originate from attempting to circumvent vital steps in the overall processing.

Some basic considerations should be:

- Know your supplier
- Try to purchase familiar alloys wherever possible
- When evaluating near net shape items, be sure to amortize non recurrent tooling costs
- Add heat treat costs for lot size anticipated
- Try for the lowest risk method
- Allow sufficient transit times between operations

- If the parts are difficult and the delivery critical - process by two (2) different methods. The cost may be slightly higher but the risks and guarantee of delivery may be more than worth it.
- Write the best specification possible for the first run. Be sure to update when further information is available so the follow-on runs will be smooth and less hectic.

In conclusion, the acid test for a well written purchase specification may not lie in a consummate set of detailed instructions, which attempts to cover all possible conditions. Nor does it lie with extreme brevity. The real asset will be with a concise, clear, adequately covered, unambiguous specification which is arranged in an easy-to-follow order, so that all the concerned parties will find it easy to read and it will achieve maximum use and acceptance.

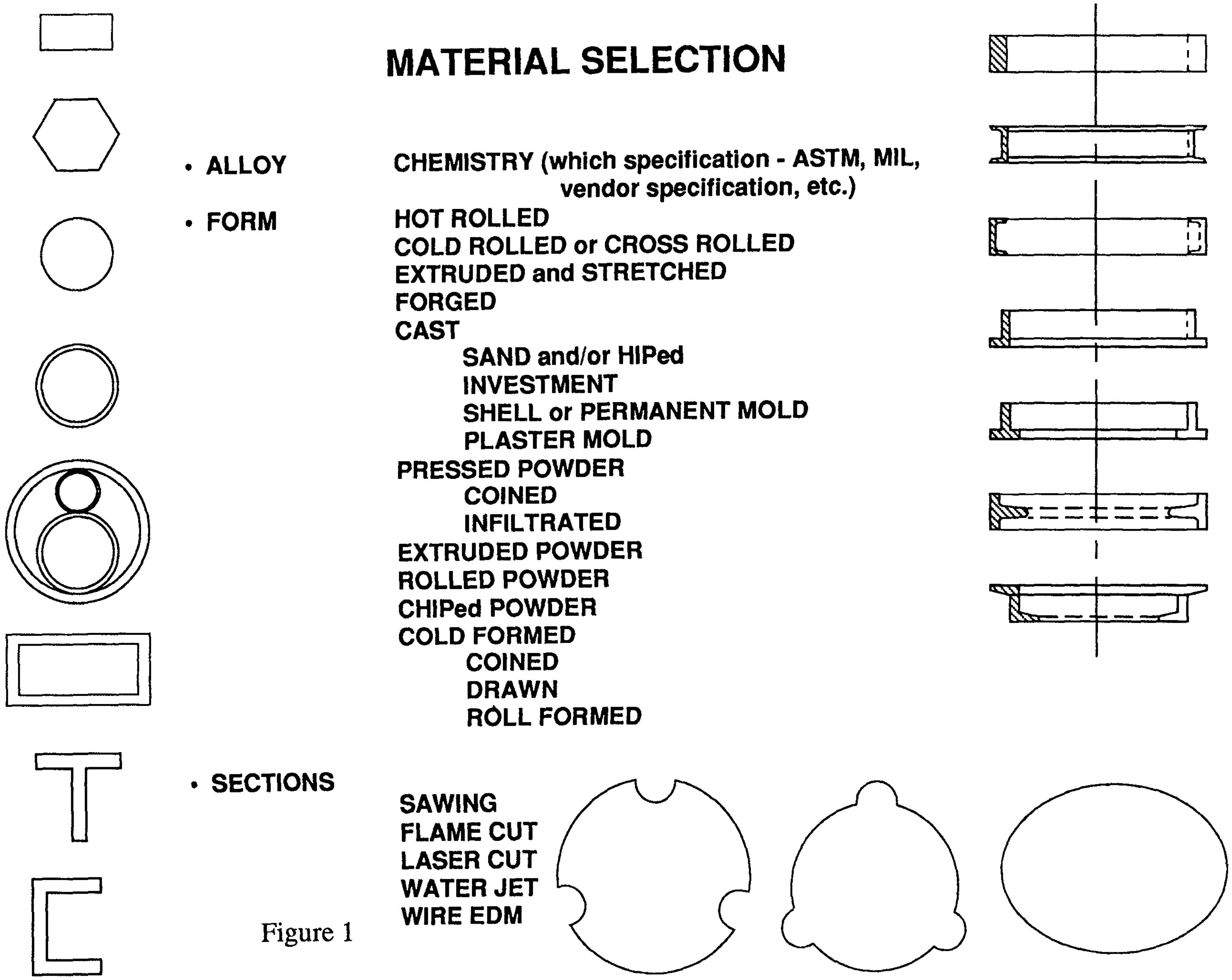

MATERIAL SELECTION
• ALLOY
CHEMISTRY (which specification - ASTM, MIL, vendor specification, etc.)
• FORM
HOT ROLLED
COLD ROLLED or CROSS ROLLED
EXTRUDED and STRETCHED
FORGED
CAST
SAND and/or HIPed
INVESTMENT
SHELL or PERMANENT MOLD
PLASTER MOLD
PRESSED POWDER
COINED
INFILTRATED
EXTRUDED POWDER
ROLLED POWDER
CHIPed POWDER
COLD FORMED
COINED
DRAWN
ROLL FORMED
• SECTIONS
SAWING
FLAME CUT
LASER CUT
WATER JET
WIRE EDM

Figure 1

MATERIAL SELECTION

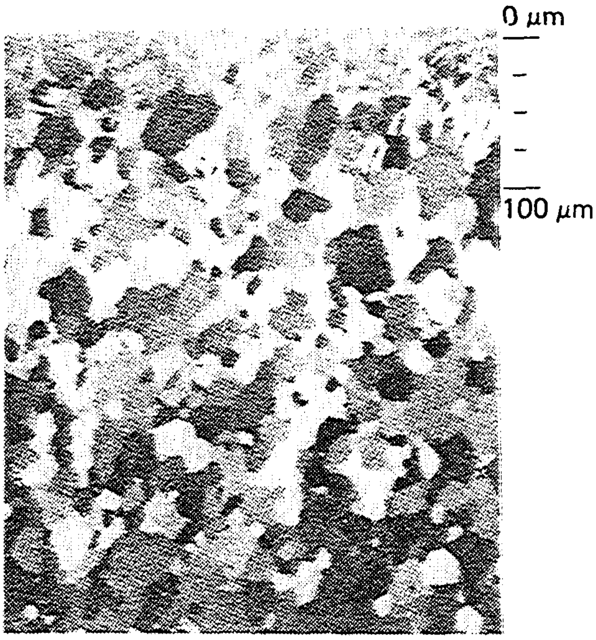
- CONDITIONS
  - TEMPER - 0, H32, H112, T4, T651
  - COLD ROLLED - 1/4 H, 1/2 H, 3/4 H, Full Hard

  MECHANICAL PROPERTIES
  - TENSILE STRENGTH
  - ELONGATION
  - MICROYIELD (PEL)
  - FRACTURE TOUGHNESS
  - HARDNESS

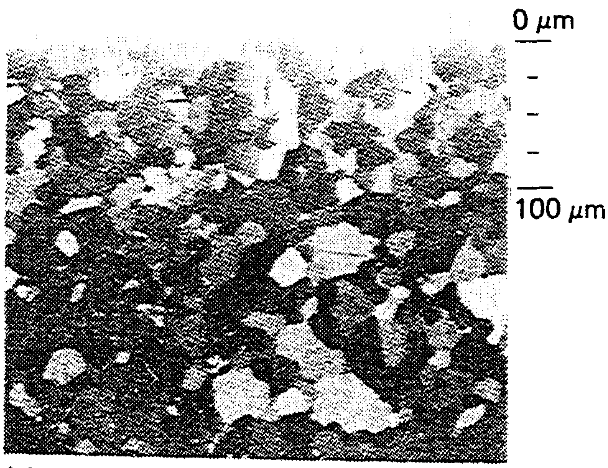
  PHYSICAL PROPERTIES
  - DENSITY
  - COEFFICIENT OF THERMAL EXPANSION (CTE)

- TESTS
  - DENSITY or THERMALLY INDUCED POROSITY (TIP)
  - DILATOMETRY
  - DYE PENETRANT
  - GRAIN SIZE
  - RADIOGRAPHIC
  - TENSILE
  - X-RAY DIFFRACTION

Figure 2

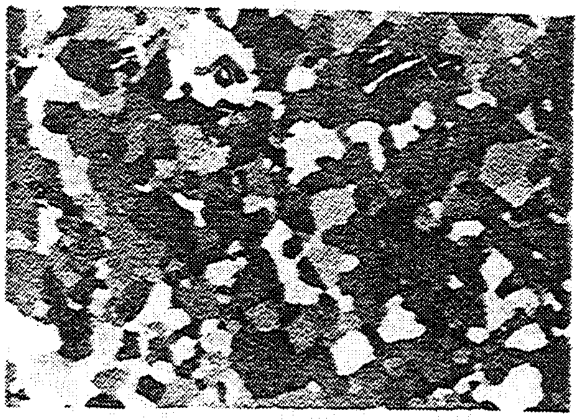


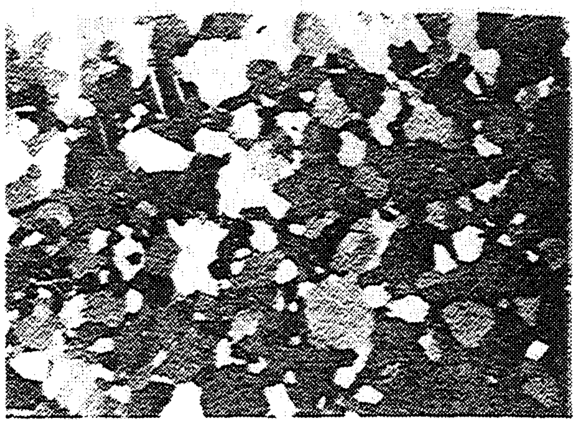
(a) As machined



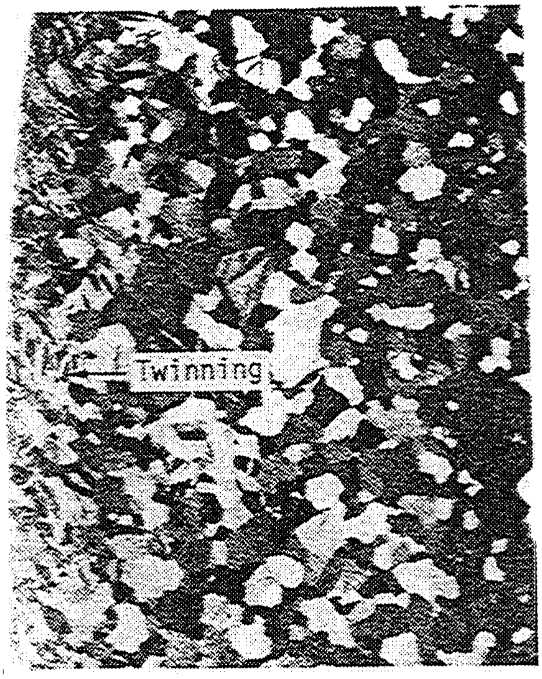
(c) 75 μm etched


(a) No heat treatment


(c) 800 °C/h


(d) 900 °C/h

Effect of etching; effect of heat treatment.
in removing machining damage.
Figure 3.

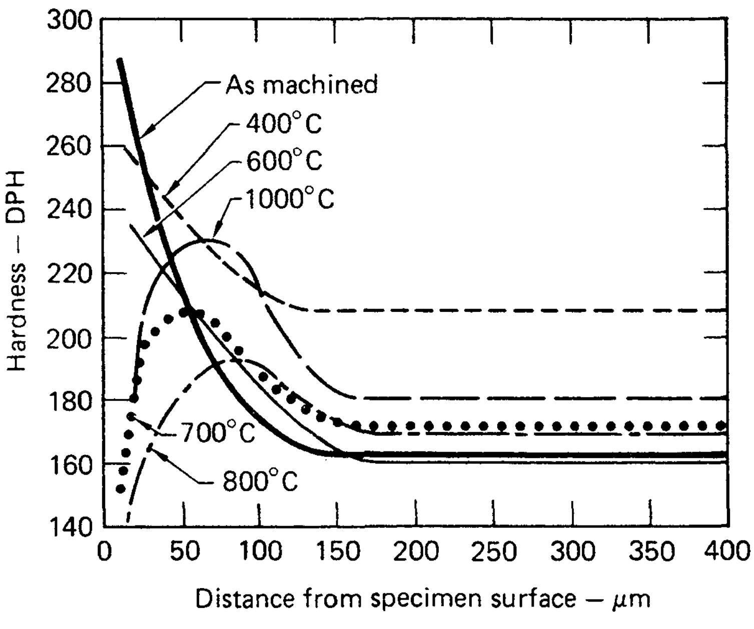


(A) Cross Section. 200x.

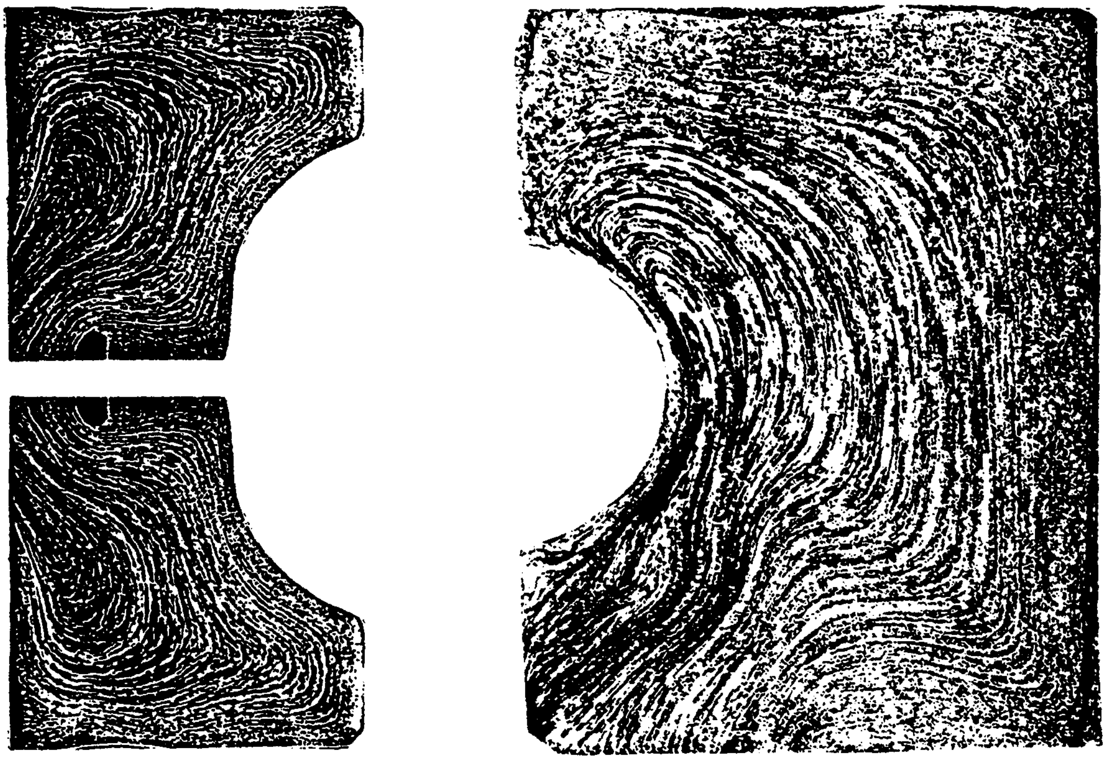
Tensile Specimen, As-machined-rough
Figure 4

(A) Cross Section. 200x

Tensile Specimen,
As-machined-rough and Etched
Figure 5

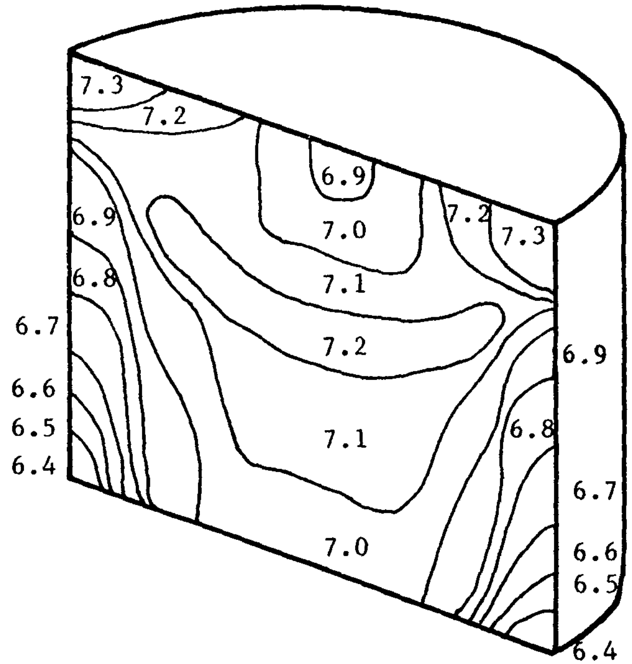


Microhardness Vs Depth from the
As-machined Surface
Restoration of Properties at 800°C
Figure 6



Seamless Shaped Rolled Rings
Figure 7

Density Greatest at the Top Outer Circumference, Least at the Outer Bottom Circumference. Near the Surface, Density Decreases Uniformly From Top to Bottom



Rigid Die Compaction of Nickel Powder
Figure 8