A METALLURGIST LOOKS AT REVERSE ENGINEERING

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REVERSE ENGINEERING
A UNIVERSAL CONCEPT

• CORPORATIONS OFTEN BENCHMARK OWN PRODUCTS VS THOSE OF COMPETITION
  – TEAR DOWN COMPETITOR’S PRODUCT
  – USE INFORMATION TO OWN ENDS

• SOUNDS LIKE REVERSE ENGINEERING?- IT IS

• FAA APPLICANTS PRODUCE REPLACEMENTS TO TYPE-CERTIFICATED PARTS, USING REVERSE ENGINEERING

• APPLICANTS STRIVE TO DEMONSTRATE SIMILARITY / IDENTICALITY TO CERTIFICATED PARTS
  – REDUCE TEST, COMPUTATION & ANALYSIS
  – COST SAVINGS TO APPLICANT
ISSUE

• PART MANUFACTURER APPROVAL PROCEDURES, ORDER 8110.42 Rev. A (31 MARCH 1999) STATES:

“WHILE APPLICANT COULD ESTABLISH THE USE OF IDENTICAL MATERIALS AND DIMENSIONS, IT IS UNLIKELY THAT A SHOWING COULD BE MADE THAT TOLERANCES, PROCESSES AND MANUFACTURING SPECIFICATIONS WERE IDENTICAL”

• PURPOSE OF BRIEFING: CHECK VALIDITY OF STATEMENT
AGENDA

- ANATOMY OF TYPE DESIGN
- THE AFTER-MARKET APPLICANT
- CHEMICAL ANALYSES
- MECHANICAL TESTING
- APPLICANT SCORE SHEET
- CONCLUSIONS
ANATOMY OF TYPE DESIGN

• FORM, FIT & FUNCTION

• MATERIALS & PROCESSES

• SUPPLIER INFORMATION

• OEM MATERIAL & PROCESS SELECTION CRITERIA
FORM & FIT

- DEPICTED ON DRAWING (DIMENSIONS, TOLERANCES, ETC.)

FUNCTION

- FUNCTIONAL / PERFORMANCE REQUIREMENTS
  - MECHANICAL, PHYSICAL, ENVIRONMENTAL
- SPECIFIED ON DRAWING OR REFERENCED SPECS
- SOMETIMES
  - SPECIFIED ON HIGHER ASSEMBLY OR NOT SPECIFIED ANYWHERE (CORPORATE MEMORY)
MATERIALS

**CALLED OUT IN MATERIAL BLOCK AND / OR GENERAL NOTES OF DRAWING**

- MATERIAL TYPE AND FORM (AISI 4130 PLATE; ETC.)
- STOCK CONDITION (ANNEALED; ROLLED; ETC.)
- STOCK SIZE
- MATERIAL SPECIFICATION
  - COMPOSITION LIMITS, MELTING PRACTICE, INSPECTION & TEST REQUIREMENTS, ETC.
- MATERIAL SUBSTITUTION INFORMATION
PROCESSES

CALLED OUT IN GENERAL NOTES SECTION

• FABRICATION OPERATIONS: HEAT TREAT, WELDING, BRAZING, FORGING, ETC.

• SURFACE TREATMENTS: COATINGS, SHOT PEENING, ETC.

• AUXILIARY PROCESSES: STRESS RELIEF, ANNEAL, ETC.

• INSPECTION: PENETRANT, MAGNETIC PARTICLE, ETC.

• PROCESS SEQUENCE: HEAT TREAT AFTER WELDING; INSPECT AFTER WELDING AND AFTER HEAT TREAT; ETC.

• TOOLING: FIXTURES, TEMPLATES, ETC.
SUPPLIER INFORMATION

PREFERRED SUPPLIERS MAY BE CALLED OUT ON DRAWING OR SPECIFICATIONS

• SPECIALIZED PROCESSING
  – CASTING, BRAZING, PLATING ON ALUMINUM OR TITANIUM, STRAIGHTENING, ETC.

• INTRICATE / SPECIALIZED COMPONENTS
  – BALL BEARINGS, GEARS, ETC.

• DIFFICULT TO PROCURE MATERIALS
  – VACUUM MELTED 4340 OR 440, 17-4 PH SHEET OR PLATE, ETC.
OEM MATERIAL & PROCESS SELECTION CRITERIA

• DESIGN REQUIREMENTS
  – MECHANICAL, PHYSICAL, ENVIRONMENTAL

• FABRICATION CONSIDERATIONS
  – FORMING, DEPTH OF HARDENING, WELDING, ETC.

• THE ECONOMY FACTOR
  – COST & AVAILABILITY OF MATERIALS & PROCESSES

• MATERIAL COST VS PROCESSING ECONOMY

• COST = MATERIAL + FABRICATION + INSPECTION + FINISHING + REWORK
AGENDA

• ANATOMY OF TYPE DESIGN
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• CHEMICAL ANALYSES
• MECHANICAL TESTING
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• CONCLUSIONS
THE AFTER-MARKET APPLICANT

• TYPE DESIGN DATA NOT AVAILABLE TO APPLICANT
  – MUST RELY ON REVERSE ENGINEERING
    😊 USING OEM PARTS ON THE MARKET

• CONFIGURATION
  – BY MEASURING PART DIMENSIONS

• MATERIAL & PROCESS REQUIREMENTS
  – ALLOY TYPE: BY CHEMICAL ANALYSES
  – HEAT TREAT: BY MECHANICAL TESTING

APPLICANT FEELS DESIGN REQUIREMENTS SUFFICIENTLY IDENTIFIED
AGENDA

- ANATOMY OF TYPE DESIGN
- THE AFTER-MARKET APPLICANT
- CHEMICAL ANALYSES
  - CHEMICAL ANALYSIS METHODS
  - WHAT APPLICANT SHOULD DO
- MECHANICAL TESTING
- APPLICANT SCORE SHEET
- CONCLUSIONS
CHEMICAL ANALYSES
METHODS

• CLASSICAL WET ANALYTICAL CHEMISTRY (DIRECT)
  – ACCURATE, TIME CONSUMING & EXPENSIVE

• INSTRUMENTAL METHODS (INDIRECT)
  – ONLY COMPARATIVE- NOT ABSOLUTE
    😊 MUST HAVE ADEQUATE STANDARDS
  – FAST & FAIRLY INEXPENSIVE

• ARC / SPARK OES (OPTICAL EMISSION SPECTROSCOPY)
  – MOST ACCEPTED METHOD

• EDS (ENERGY DISPERSIVE X-RAY SPECTROMETRY)
  – FREQUENTLY USED BY APPLICANTS
OES
CONSIDERATIONS / LIMITATIONS

• EXIT SLITS SET BY MANUFACTURER
  – SUITABLE FOR ONLY SOME ALLOY GROUPS

• RESULTS CAN VARY FROM LAB TO LAB
  – SPECTROMETER, STANDARDS & LINES USED
  – MONOCHROMATOR FOR A TRUE UNKNOWN

• NOT FOR ALL ELEMENTS
  – OLDER AIR-PASS SPECTROMETERS- NO C, S OR P
  – OES NOT YET ACCEPTED FOR H, O OR N
EDS
LIMITATIONS

• ONLY SMALL VOLUME ANALYZED
  – NOT REPRESENTATIVE OF BULK CHEMISTRY

• MANY SYSTEMS CANNOT DETECT O, C, N, Be, Li, B

• SOME ENERGY PEAKS COINCIDE
  – DIFFICULT TO IDENTIFY GENERATING ELEMENT

• QUANTITATIVE ANALYSES REQUIRE STANDARDS
  – EVEN WITH STANDARDS
    😞 METHOD NOT ACCEPTED AS OES
    😞 SUPPLEMENT BY OTHER METHODS
CHEMICAL ANALYSIS
WHAT APPLICANT SHOULD DO

**SHOULD “INTERROGATE” LAB**

- METHOD USED & ITS SUITABILITY FOR ELEMENTS PRESENT; CONCENTRATIONS IN STANDARDS; SUPPLEMENTAL METHODS USED; ETC.
- IF EDS WAS USED, REQUEST ANOTHER METHOD

**SHOULD CONSULT**

- WITH A CHEMIST
  - SUITABILITY & ACCURACY OF METHOD(S) USED
- WITH MILLS, CONSULTANTS, CSTA-METALLURGY
  - SELECTIONS IN SIMILAR APPLICATIONS IN INDUSTRY
CHEMICAL ANALYSIS
WHAT APPLICANT SHOULD DO

SHOULD VALIDATE RESULTS IF IN DOUBT

• GET SAMPLE OF ALLOY PROPOSED BY LAB

• SUBMIT SAMPLE + OEM MATERIAL TO DIFFERENT LAB
  – FOR COMPARISON

• REMEMBER
  – MANY ALLOYS CLOSE IN CHEMISTRY
    ☹ SUPERALLOYS; CRES STEELS; 4340 & 300M; OTHERS
  – BUT NOT IN PERFORMANCE

INCORRECT ANALYSIS ⇒ PROBLEMS LATER ON
AGENDA

• ANATOMY OF TYPE DESIGN
• THE AFTER-MARKET APPLICANT
• CHEMICAL ANALYSES
• MECHANICAL TESTING
  – HARDNESS
  – HARDNESS & CONDUCTIVITY
  – TENSILE
  – ISSUES IN MECHANICAL TESTING
• APPLICANT SCORE SHEET
• CONCLUSIONS
MECHANICAL TESTING

• PERFORMED TO
  – DETERMINE ALLOY HEAT TREAT / TEMPER

• TWO APPROACHES EXIST
  – INDIRECT METHODS
    ☹ HARDNESS
    ☹ HARDNESS AND CONDUCTIVITY
  – THE DIRECT METHOD
    ☺ TENSILE TESTING

• APPLICANTS PREFER INDIRECT METHODS
  – NONDESTRUCTIVE
  – LESS EXPENSIVE
INDIRECT METHODS
HARDNESS TESTING

• HARDNESS SENSITIVE MEASURE OF HEAT TREATMENT
  – FOR MANY STEELS (41XX, 43XX, 300M, 440, ETC.)

• HARDNESS-STRENGTH RELATIONSHIPS EXIST
  – CONSISTENT & REPRODUCIBLE (ASTM A370)

• TO DETERMINE STEEL HEAT TREATMENT
  – MEASURE HARDNESS & CONVERT TO STRENGTH
  – FIND CORRESPONDING HEAT TREAT DETAILS
    😊 FROM AMS 2759, OTHER SPECS, DATA SHEETS, ETC.

• OFTEN, NO NEED TO CONVERT TO STRENGTH
  – HEAT TREAT RELATED DIRECTLY TO HARDNESS
HARDNESS TEST LIMITATIONS

• HARDNESS GENERALLY NOT SENSITIVE MEASURE OF HEAT TREATMENT / TEMPER
  – FOR NONFERROUS ALLOYS
  – FOR AUSTENITIC & PH CRES STEELS
  – MARAGING STEELS

• NO HARDNESS-STRENGTH RELATIONSHIPS

• ∴ HARDNESS CANNOT BE USED TO DETERMINE HEAT TREAT DETAILS
INDIRECT METHODS
ALUMINUM ALLOYS

• VARIOUS (T) AND (O) TEMPERS IDENTIFIED BY
  – MEASURING HARDNESS & CONDUCTIVITY
    😊 AMS 2658

• TEMPER FOR PARTICULAR ALLOY IDENTIFIED WHEN
  – HARNESS WITHIN SPECIFIED RANGE
    AND
  – CONDUCTIVITY WITHIN SPECIFIED RANGE

• METHOD NOT APPLICABLE TO
  – STRAIN HARDENED (H) TEMPERS
  – CASTINGS
THE DIRECT METHOD
TENSILE TESTING

• **USUALLY PERFORMED PER ASTM E 8**
  – ON SAMPLES MACHINED FROM PART

• **PART SIZE IMPOSES LIMITS ON**
  – SAMPLE LENGTH
    ☹ **AFFECTS GRIP & GAGE LENGTHS**
    -- GAGE LENGTH ↓: STRENGTH ↓ & DUCTILITY ↑
  – NUMBER OF SAMPLES & CONFIDENCE LEVEL

• **∴ SMALL PARTS CAN RENDER TEST IMPOSSIBLE**
  – RELY ON INDIRECT METHODS
    ☹ **SUBJECT TO THEIR LIMITATIONS**
ISSUES IN MECHANICAL TESTING
DRAWING CALLOUTS

• DRAWINGS CALL OUT STRENGTH / HARDNESS
  – AS A RANGE (e.g., HRC 50-54)
  – AS A MINIMUM (e.g., HRC 50 MIN.)

• APPLICANT HAS NO ACCESS TO OEM DRAWING

HOW DO APPLICANT’S RESULTS RELATE TO DRAWING CALLOUT?
ISSUES IN MECHANICAL TESTING
NON-EQUIVALENT SPECIFICATIONS

• INCONEL 718 SHEET: AMS 5596 AND AMS 5597
  – DIFFERENT HEAT TREATMENTS
  – DIFFERENT CREEP PROPERTIES
  – NEARLY IDENTICAL TENSILE PROPERTIES

• AISI 4340 BAR: Mil-S-5000 (AIR MELTED) AND Mil-S-8844 (VACUUM MELTED)
  – IDENTICAL TENSILE PROPERTIES & HARDNESS
  – MIL-S-8844 HAS SUPERIOR TOUGHNESS AND LOW TEMPERATURE PROPERTIES

TENSILE (OR HARDNESS) TESTING
MAY NOT REVEAL ALL PROPERTY ASPECTS
AGENDA

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• MECHANICAL TESTING
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• CONCLUSIONS
APPLICANT SCORE SHEET
FORM, FIT & FUNCTION

• FORM
  – FROM OEM PART DIMENSIONS

• FIT
  – DIMENSIONS FROM SMALL NUMBER OF PARTS
  – OEM TOLERANCES NOT KNOWN

  WILL ALL PARTS FIT & BE INTERCHANGEABLE?

• FUNCTION
  – OEM FUNCTIONAL TESTS NOT KNOWN

  DID APPLICANT PERFORM RELEVANT FUNCTIONAL TESTS?
  IF NOT, WILL PART PERFORM INTENDED FUNCTION?
APPLICANT SCORE SHEET
MATERIALS & PROCESSES

• MATERIAL TYPE DETERMINED
  - BY CHEMICAL ANALYSIS
    😞 SUBJECT TO LIMITATIONS

• HEAT TREAT / TEMPER DETERMINED
  - BY MECHANICAL TESTING
    😞 SUBJECT TO LIMITATIONS

• MELTING PRACTICE; INSPECTION; AUXILIARY PROCESSES; MANUFACTURING SPECIFICATIONS; PROCESS SEQUENCE
  - NOT ADDRESSED

∴ MATERIAL & PROCESS CHARACTERIZATION INCOMPLETE
APPLICANT SCORE SHEET
OTHER FACETS OF TYPE DESIGN

• SUPPLIER INFORMATION
  - NOT AVAILABLE
    😞 WHAT IF OEM USED A SPECIAL SUPPLIER, SAY IN SWEDEN

• OEM MATERIAL & PROCESS SELECTION CRITERIA
  - NOT AVAILABLE
    😞 WHAT IF OEM MATERIAL IS NOT AVAILABLE TO APPLICANT
      -- ON WHAT BASIS CAN APPLICANT SELECT AN ALTERNATE MATERIAL?
CONCLUSIONS

• COMMONLY USED REVERSE ENGINEERING PRACTICES
  - DO NOT REVEAL MANY TYPE DESIGN FACETS

• THE STATEMENT CONTAINED IN ORDER 8110.42 REV. A (31 MARCH 1999) IS VALID

“WHILE APPLICANT COULD ESTABLISH THE USE OF IDENTICAL MATERIALS AND DIMENSIONS, IT IS UNLIKELY THAT A SHOWING COULD BE MADE THAT TOLERANCES, PROCESSES AND MANUFACTURING SPECIFICATIONS WERE IDENTICAL”