- FRICTION STIR WELDING -
A brief Review and Perspective for the Future

Dr. Tracy W. Nelson
Department of Mechanical Engineering
Brigham Young University
Provo, UT

Outline

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- Annals of FSW
- Tool Design
- Tool design and Material flow
- Process Control
- Process Modeling
- Perspective for the future
- Summary

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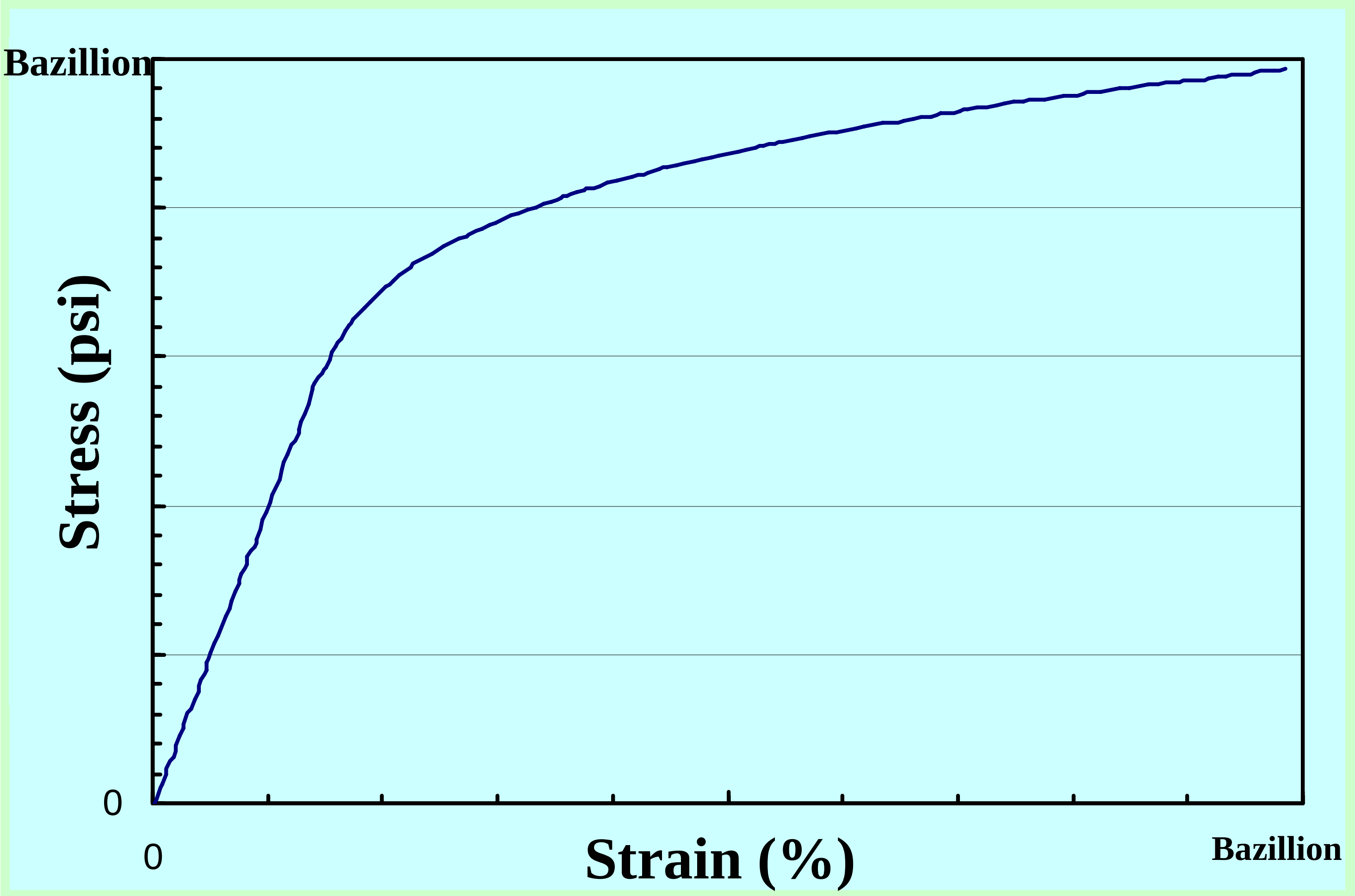
Annals of FSW

- **My first impressions**



Annals of FSW

- **Who thought of such a process?**

- **Who have aided in the progress of FSW?**

Annals of FSW

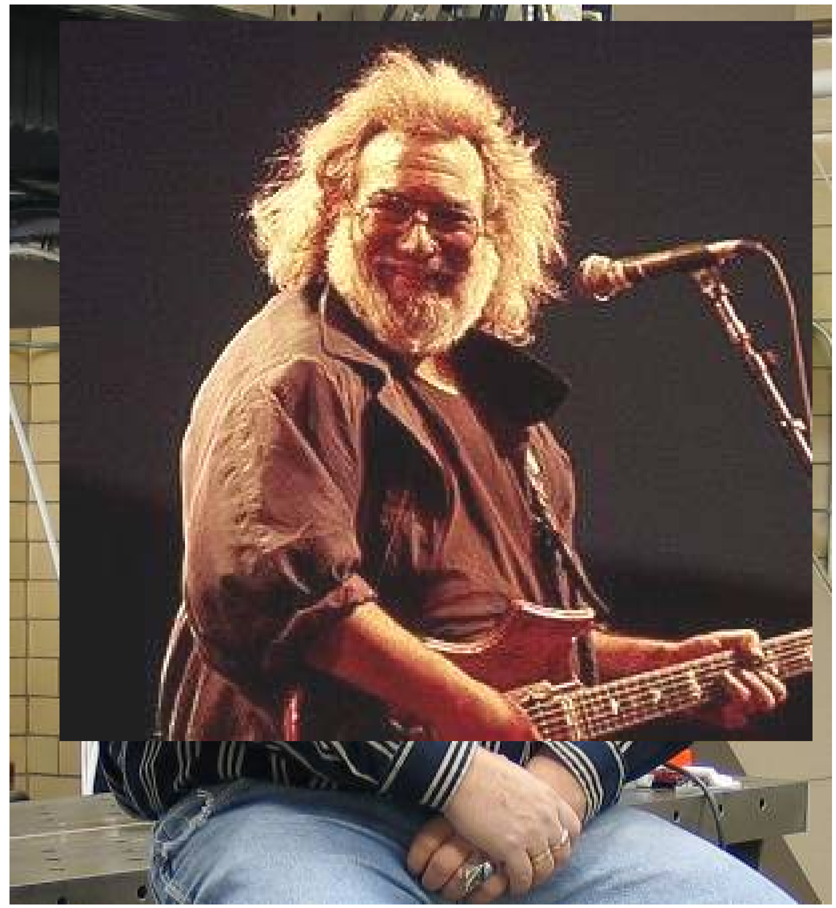
- **Patented in 1991 by The Welding Institute**
- **A great joining process, which when finished the result looks like a bad machining job!!**
- **Who is Wayne Thomas?**

Annals of FSW

- **The Welshman, Wayne Thomas**
  - The man behind the invention?

Annals of FSW

- **Bill Arbegast**



FSW Tool Design

- **Originally very simple designs**
  - Produced excellent weld quality and repeatability
  - Able to weld the unweldable
  - Hydro Aluminium (Ole Midling) ran their first XXX Km of weld with this tool
- **Material flow?**
  - 1st ISFSW in thousand Oaks, CA
  - It only took about a decade for consensus:

Original type tool design

Material flows around the pin tool!

FSW Tool Design

- **Changed dramatically over the years**
  - Now very complex
  - Reported benefits;
    - reduced loads,
    - increased travel speeds,
    - improved tensile properties,
    - reduced asymmetry

- **Any disadvantages?**

Tri-Flute type tool

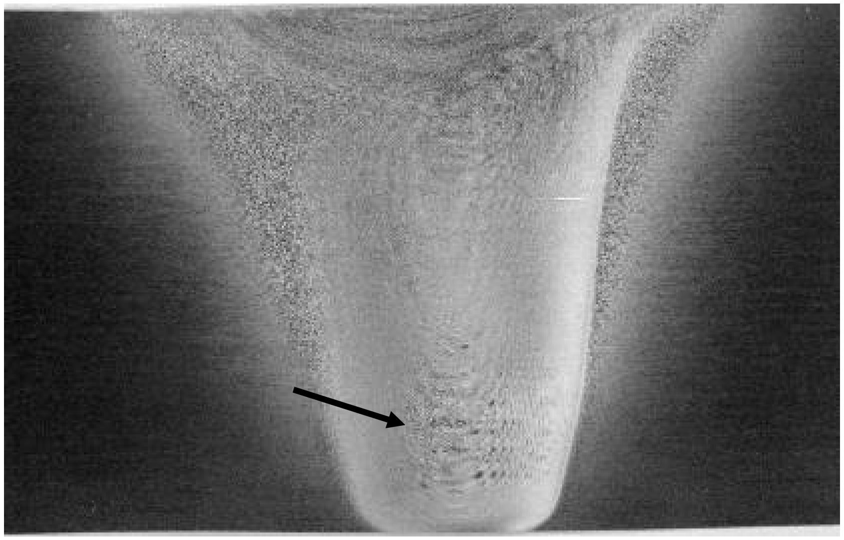
A-skew™ tool

FSRL
Friction Stir Research Laboratory

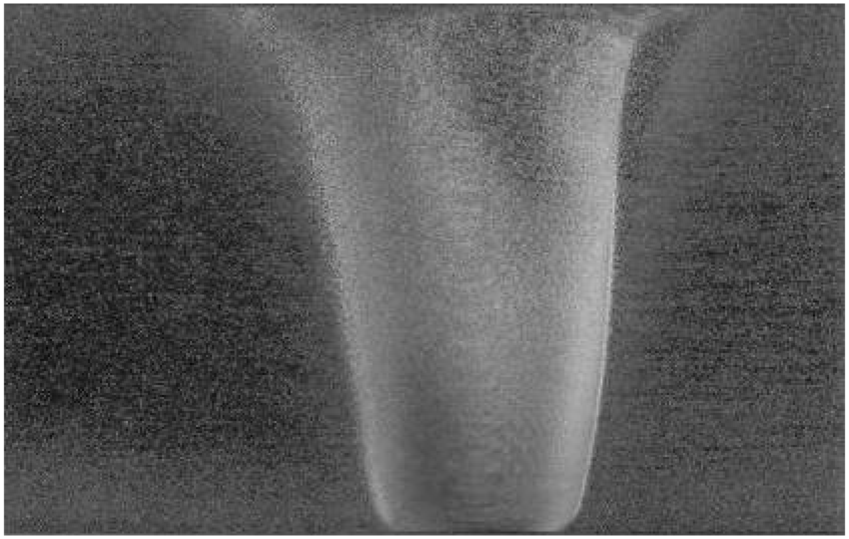
BYU

Tool Design and Material Flow

- **Disadvantages to these unique tool designs**
  - In-situ abnormal grain growth



2.0 in/min travel speed, 275 rev/min
(Courtesy CTC, K. Colligan)



same tool at 4.0 in/min travel speed, 275 rev/min

- **Why?**

Tool Design and Material Flow

- **FSW of Steels has met many of the same challenges**
  - Added difficulties:
    - Lower thermal conductivity, and
    - Tool wear
      - Higher temperatures, chemical and physical wear are serious problem
        - » Tool design has previously been limited

Tool Design and Material Flow

- **Despite challenges, tool design for HTM has progressed**
  - First tools were very simple (1^{st} ISFSW)
    - Feature on the pin tool were quickly worn away
    - Maximum tool life reported?
  - PBCN tool was introduced (2000)
    - Pin tool was large and features simple
    - Maximum tool life reported, 80m (4^{th} ISFSW)

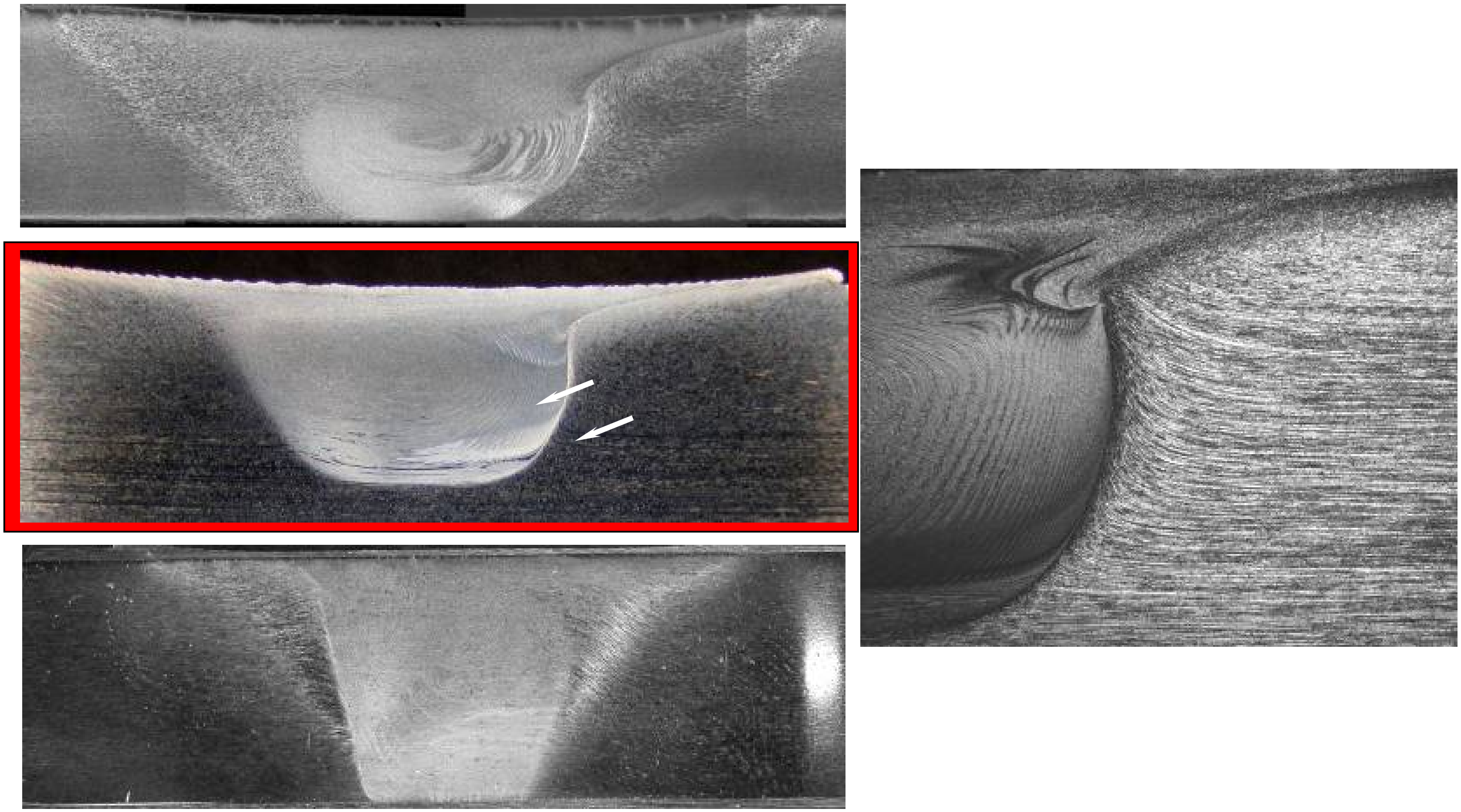
PCBN tool evolution →

Tool Design and Material Flow

- **12 mm step spiral threaded PCBN tools (2004)**
  – Made possible by development of new PCBN grades

Tool Design and Material Flow

- **Aluminum or steel?**



Tool Design and Material Flow

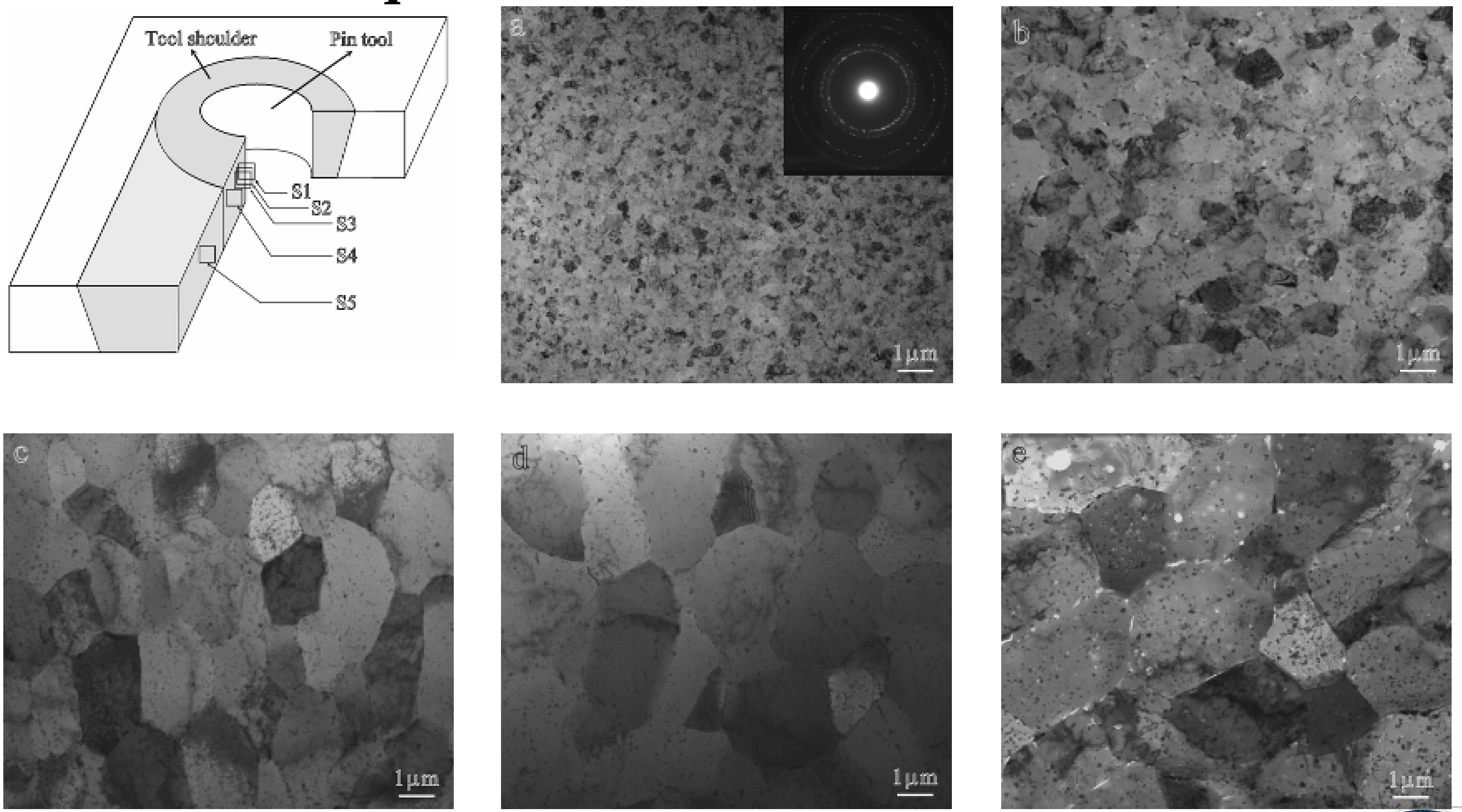
- **Ultimately, tool design effects material flow, e.g.**
  - Strain and strain rates,
  - Heating and peak temperatures
  - Ability to make a sound weld
- **As a community, we lack the fundamentals**
  - e.g. What is the optimum tool design?!
    - Probably material and objective dependant
    - Can not be answered without answering the above
- **The answers to these questions are essential for technology evolution**

Microstructural Evolution

- **Another area of considerable debate**
- **Hypotheses include:**
  - Dynamic recrystallization
  - Continuous dynamic recrystallization
  - Subgrain development
  - Classical recrystallization
- **Microstructural evolution in FSW&P is dependant**
  - strain
  - strain rate
  - velocity and
  - temperature gradients
  - Material/alloy
- **FSW&P produces a very fine grain size (1-10 μm)**

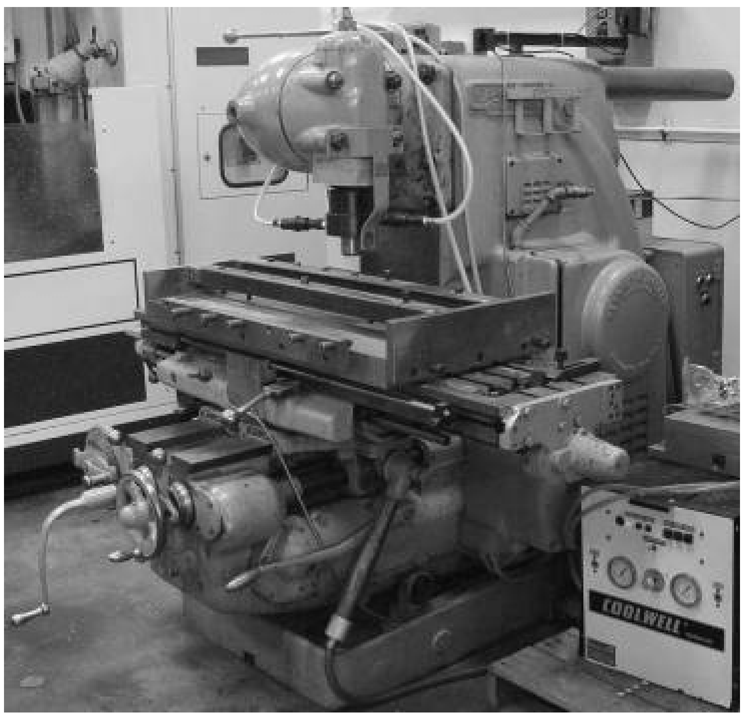
Microstructural Evolution

- **Su: in-situ quenched of exit hole**



Evolution of Process Control

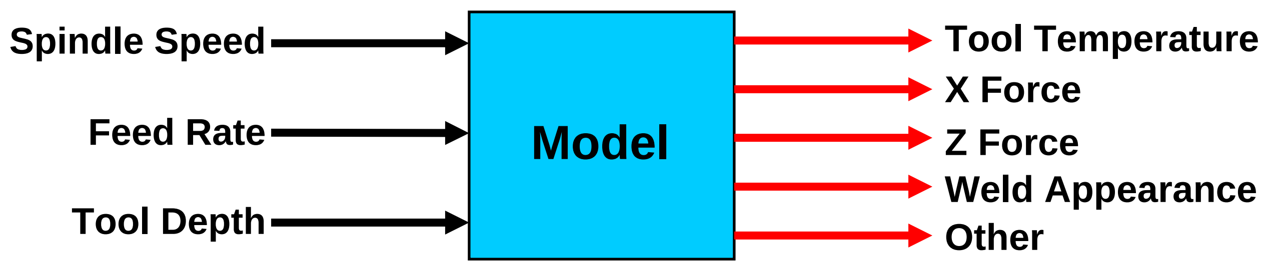
- **Process capabilities has evolved much faster than the process fundamentals**
  - First machines were hand-eyeball coordination (HEBC) control system
  - New machines measure force/torque/power/speed on every axis



Our Evolution of Process Control

Process Modeling

- **Computational and empirical models are essential to the future of FSW**
  - These will help elucidate many of the fundamental principle presently unknown
  - Validation of models require carefully planned experiments
    - Marker studies (Colligan, Reynolds and London) to validate flow
    - Characterize the nature of heat generation and dissipation (Schmidt, Covington, Pew)
    - Assess the physics of the tool/weld metal interface (Stratton)
    - Relationships between process inputs and measured outputs (Record)



Relationship between process inputs and measured outputs

Perspective for the Future

Summary

- **Technology has come a long way**
  - Many applications in aluminum and copper
  - Faster travel speeds and improved post weld properties
- **To advance to the next level, process fundamentals must be better understood**
- **More fundamental research required**
  - Nature of material deformation and heat generation
  - physics of the tool/weld metal interface
  - Relationships between process inputs (tool design/RPM/travel speed/tool depth) and measured outputs (forces/torques/tool temperatures)