Coating Method

Die Failure

Failure Analysis

- การวิเคราะห์ความเสียหายเป็นการสืบหาสาเหตุของการเสียหายเพื่อป้องกันไม่ให้เกิดการเสียหายแบบเดิมอีก
- ก่อนที่จะมีการวิเคราะห์ความเสียหาย ข้อมูลทุกอย่างที่เกี่ยวกับชิ้นงานที่เสียหาย จำเป็นที่จะต้องมีการศึกษา
- เครื่องมือที่ใช้ในการวิเคราะห์มีหลายชนิดตั้งแต่แว่นขยาย จนถึง กล้องจุลทรรศน์

ขั้นตอนการวิเคราะห์ความเสียหาย

- สืบค้นประวัติของชิ้นงานที่เสียหาย
- ตรวจสอบรอยแตก
- วิเคราะห์ลักษณะการเสียหายที่เกิดขึ้น
- ศึกษาสมบัติของวัสดุที่เกี่ยวข้องกับการแตกหัก
- นำข้อมูลทั้งหมดมาประมวลหาสาเหตุของการเสียหาย

การเลือกชิ้นงาน

- เลือกทั้งส่วนที่มีการเสียหาย และไม่เสียหาย
- ควรรักษาผิวหน้าให้อยู่ในสภาพที่สมบูรณ์
- การตัดชิ้นงานจะต้องระมัดระวังไม่ให้เกิดความร้อน จนทำให้โครงสร้างเปลี่ยน
- การเก็บชิ้นงานควนเก็บในถุงพลาสติกที่ปิดผนึกได้
- ในกรณีที่ชิ้นงานมีโอกาสเกิดสนิมได้ง่าย อาจจะต้องใส่สารดูดความชื้น

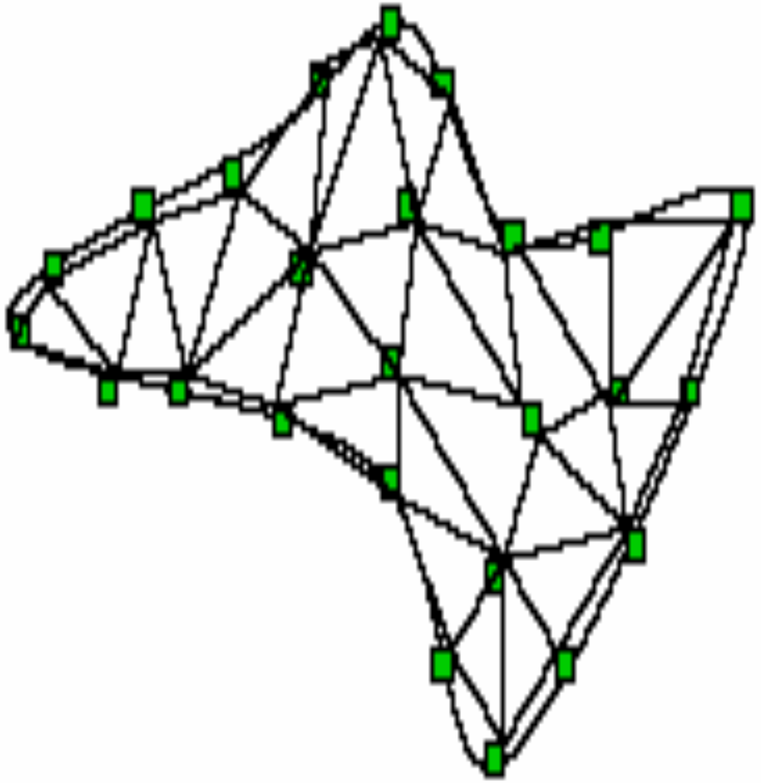
สืบค้นประวัติของชิ้นงานที่เสียหาย

- สำหรับประวัติของชิ้นงานที่เสียหายจะรวมถึงประวัติการผลิตและการออกแบบชิ้นงานด้วย
- ในขั้นตอนนี้จะรวมถึงการวิเคราะห์สภาวะการใช้ ซึ่งจะรวมถึง stress อุณหภูมิ บรรยากาศการใช้งาน
- สำหรับการวิเคราะห์สภาวะการใช้งานนั้นอาจจะใช้การวัดค่าจากสภาวะการใช้งานจริงจนถึงการสร้างแบบจำลองด้วย Finite Element Method

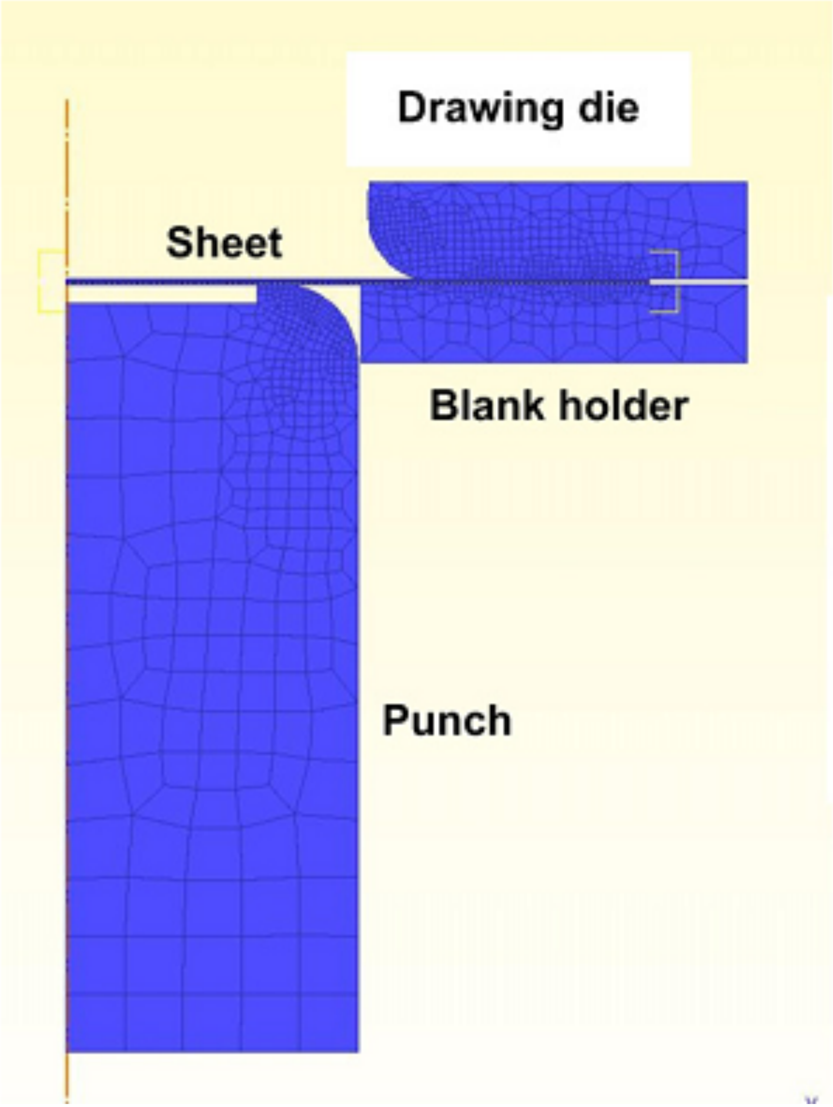
คำถามที่ต้องถาม

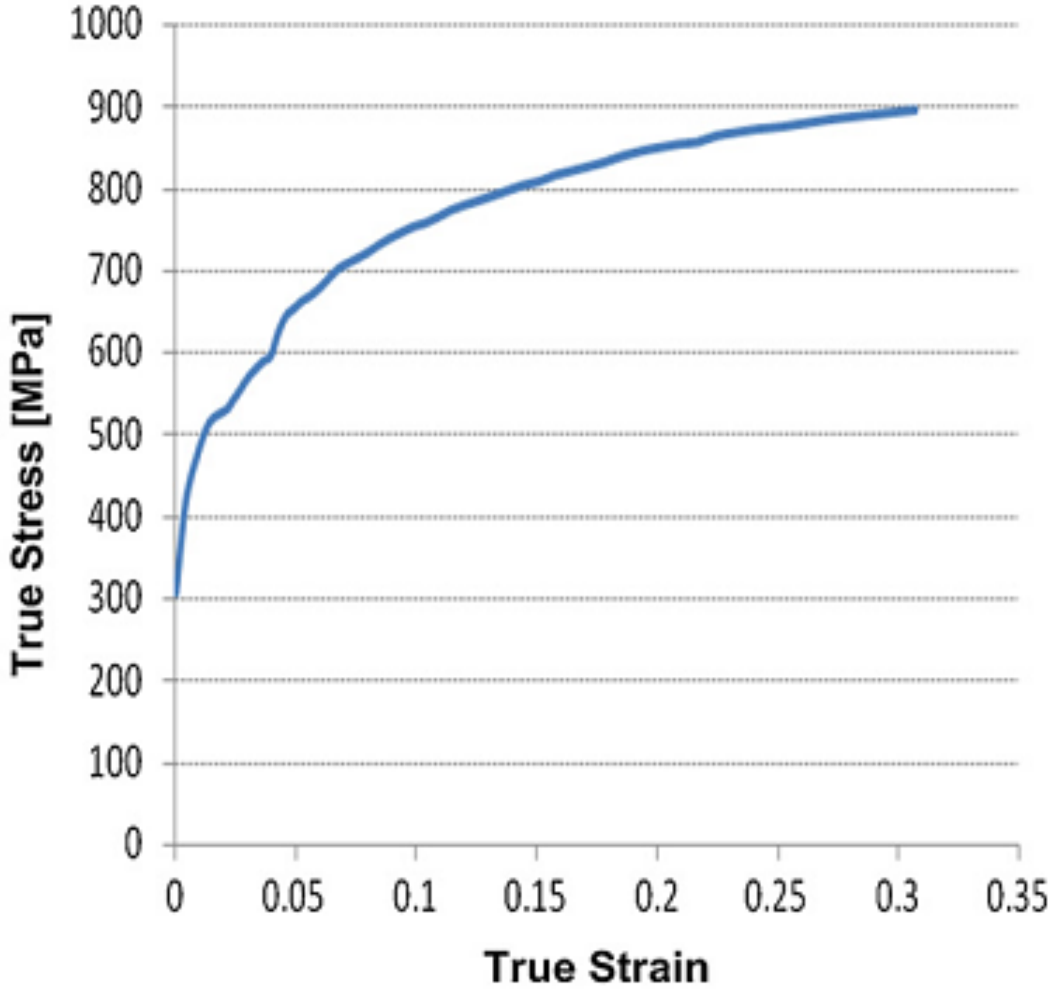
- วัสดุเป็นชิ้นส่วนอะไร
- ชิ้นส่วนที่เสียหายผลิตมาอย่างไร และมีการปรับปรุงสมบัติหลังการผลิตหรือไม่
- ชิ้นส่วนที่เสียหายทำงานเป็นปกติหรือไม่
- ชิ้นส่วนที่เสียหายมีอายุมากกว่าที่คาดไว้หรือไม่
- ชิ้นส่วนที่เสียหายมีการประกอบอย่างถูกต้องหรือไม่

การประยุกต์ใช้ FEM ในการหาค่า stress



- Finite element method เป็นวิธีการทางคณิตศาสตร์ วิธีการหนึ่งที่ถูกนำมาใช้งาน ในการหาค่า stress อย่าง กว้างขวาง
- วิธีการนี้สามารถใช้ช่วยใน การตรวจสอบค่า stress ที่ได้ จากการออกแบบด้วย และใช้ ในการหาค่า thermal stress และ residual stress ได้ด้วย





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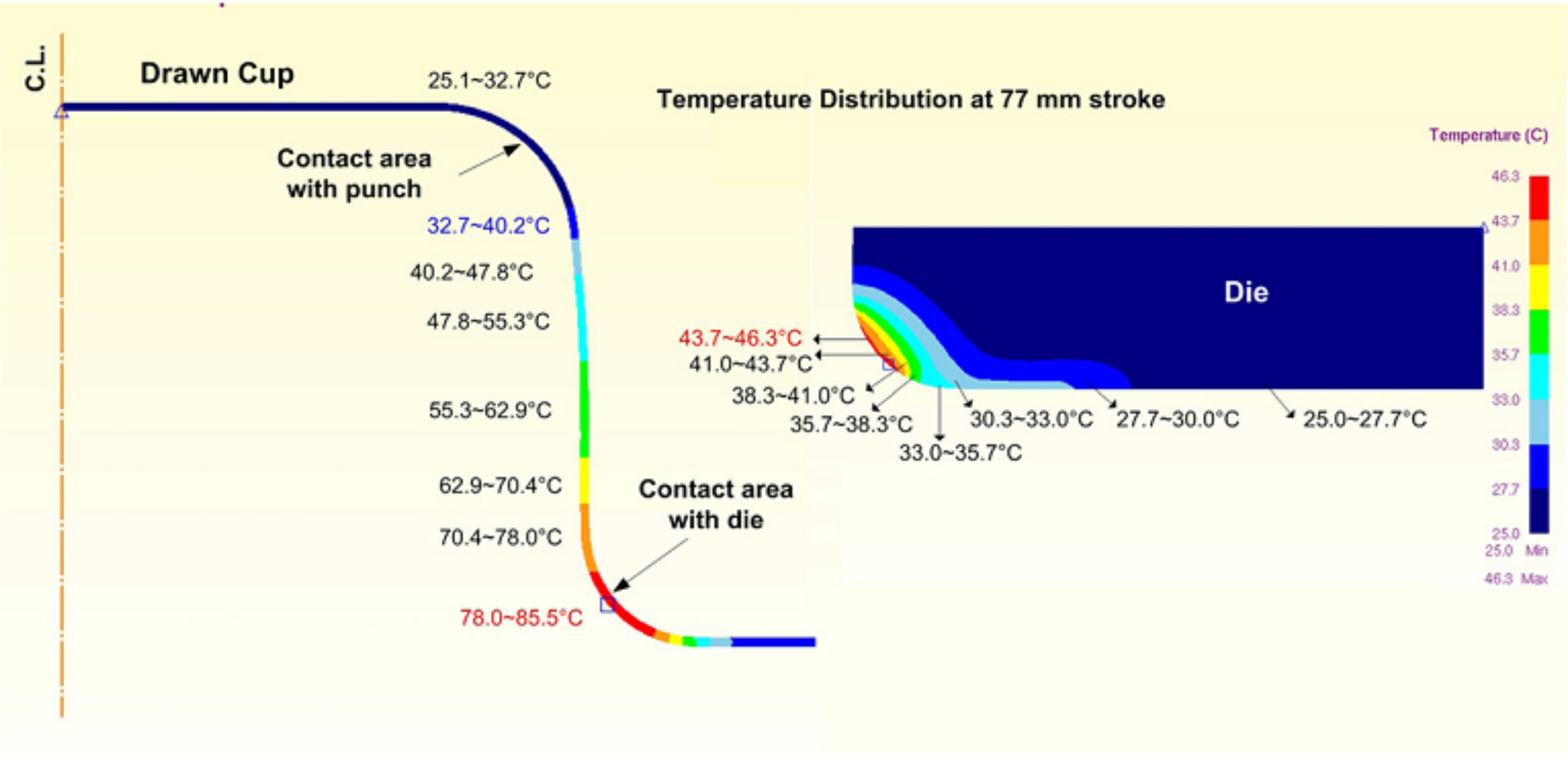


H. Kim et al. / Journal of Materials Processing Technology 209 (2009) 4122–4133

Group	Identifying symbol
Water-hardening tool steels	W
Shock-resisting tool steels	S
Oil-hardening cold-work tool steels	O
Air-hardening, medium-alloy cold-work tool steels	A
High-carbon, high-chromium cold-work tool steels	D
Mold steels	P
Hot-work tool steels, chromium, tungsten, and molybdenum	H
Tungsten high-speed tool steels	T
Molybdenum high-speed tool steels	M

Table	AISI	C	Mn	Si	W	Cr	V	Mo
510		.95	0.30	0.30		4.0		
511		.95	0.30	0.30		4.0	0.50	0.50
512		.60	0.30	0.30		4.0	0.75	0.50
513	S7	.50	0.70	0.30		3.25		1.40
514		.50	0.30	0.90		3.25	0.25	1.40

Type	AISI	C	Mn	Si	Cr	Ni	V	Mo	W
520	H-11	0.35	0.30	1.00	5.00		0.40	1.50	
521	H-13	0.35	0.30	1.00	5.00		1.00	1.50	
522	H-12	0.35	0.30	1.00	5.00		0.40	1.50	1.50
523		0.40	0.60	1.00	3.50		1.00	1.00	1.25
524	H-10	0.40	0.55	1.00	3.25		0.40	2.50	
525		0.35	0.30	1.00	5.00			2.00	

Type	AISI	C	Mn	Si	Cr	V	W	Mo	Co
530	H14	0.40	0.30	1.00	5.00	0.25	5.00	0.25	0.50
531	H19	0.40	0.30	0.30	4.25	2.00	4.25	0.40	4.25
532		0.45	0.75	1.00	5.00	0.50	3.75	1.00	0.50
533		0.35	0.60	1.50	7.25		7.25		
534		0.45	0.60	1.50	7.25		7.25		
535	H16	0.55	0.60	0.90	7.00		7.00		
536	H23	0.30	0.30	0.50	12.00	1.00	12.00		

Type	AISI	C	Mn	Si	Cr	Ni	V	Co	W	Mo
540	H21	0.35	0.30	0.30	3.50		0.50		9.00	
541	H20	0.35	0.30	0.30	2.00		0.50		9.00	
542		0.30	0.30	0.30	2.75	1.75	0.30		10.00	0.25
543	H22	0.35	0.30	0.30	2.00		0.40		11.00	
544		0.30	0.30	0.30	2.50		0.40	3.60	12.00	
545	H25	0.25	0.30	0.30	4.00		1.00		15.00	
546		0.40	0.30	0.30	3.50		0.40		14.00	
547	H24	0.45	0.30	0.30	3.00		0.50		15.00	
548		0.35	0.30	0.30	4.00	2.50			14.00	2.00
549	H26	0.50	0.30	0.30	4.00		1.00		18.00	

Type	AISI	C	Mn	Si	Cr	Ni	V	W	Mo	Co
550	H15	0.35	0.30	0.40	3.75		0.75	1.00	6.00	
551	H15	0.40	0.30	0.50	5.00		0.75	1.00	5.00	
552	H43	0.55	0.30	0.30	4.00		2.00		8.00	
553	H42	0.65	0.30	0.30	4.00		2.00	6.40	5.00	
554	H41	0.65	0.30	0.30	4.00		1.00	1.50	8.00	
555		0.30	0.50	0.30		3.00			3.00	
556		0.10	0.30	0.30	3.50		0.50	4.00	5.00	25.00

Air-hardening, medium-alloy, cold-work steels										
A2	T30102	0.95-1.05	1.00 max	0.50 max	4.75-5.50	0.30 max	0.90-1.40	...	0.15-0.50	...
A3	T30103	1.20-1.30	0.40-0.60	0.50 max	4.75-5.50	0.30 max	0.90-1.40	...	0.80-1.40	...
A4	T30104	0.95-1.05	1.80-2.20	0.50 max	0.90-2.20	0.30 max	0.90-1.40	...	...	...
A6	T30106	0.65-0.75	1.80-2.50	0.50 max	0.90-1.20	0.30 max	0.90-1.40	...	...	...
A7	T30107	2.00-2.85	0.80 max	0.50 max	5.00-5.75	0.30 max	0.90-1.40	0.50-1.50	3.90-5.15	...
A8	T30108	0.50-0.60	0.50 max	0.75-1.10	4.75-5.50	0.30 max	1.15-1.65	1.00-1.50	...	...
A9	T30109	0.45-0.55	0.50 max	0.95-1.15	4.75-5.50	1.25-1.75	1.30-180	...	0.80-1.40	...
A10	T30110	1.25-1.50[c]	1.60-2.10	1.00-1.50	...	1.55-2.05	1.25-1.75		...	...

High-carbon, high-chromium, cold-work steels										
D2	T30402	1.40-1.60	0.60 max	0.60 max	11.00-13.00	0.30 max	0.70-1.20	. . .	1.10 max	...
D3	T30403	2.00-2.35	0.60 max	0.60 max	11.00-13.50	0.30 max	. . .	1.00 max	1.00 max	...
D4	T30404	2.05-2.40	0.60 max	0.60 max	11.00-13.00	0.30 max	0.70-1.20	. . .	1.00 max	...
D5	T30405	1.40-1.60	0.60 max	0.60 max	11.00-13.00	0.30 max	0.70-1.20	. . .	1.00 max	**2.50-3.50**
D7	T30407	2.15-2.50	0.60 max	0.60 max	11.50-13.50	0.30 max	0.70-1.20	. . .	3.80-4.40	...

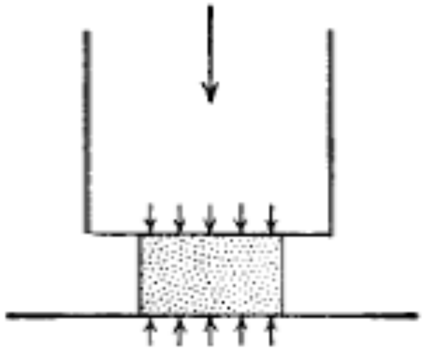
Oil-hardening cold-work steels										
O1	T31501	0.85-1.00	1.00-1.40	0.50 max	0.40-0.60	0.30 max	. . .	0.40-0.60	0.30 max	. . .
O2	T31502	0.85-0.95	1.40-1.80	0.50 max	0.50 max	0.30 max	0.30 max	. . .	0.30 max	. . .
O6	T31506	1.25-1.55[c]	0.30-1.10	0.55-1.50	0.30 max	0.30 max	0.20-0.30	. . .	. . .	. . .
O7	T31507	1.10-1.30	1.00 max	0.60 max	0.35-0.85	0.30 max	0.30 max	1.00-2.00	0.40 max	. . .

United States (AISI)	West Germany (DIN)[a]	Japan (JIS)[b]	Great Britain (B.S.)[c]	France (AFNOR)[d]	Sweden (SS_{14})
Air-hardening, medium-alloy, cold-work steels (ASTM A 681)					
A2	1.2363	G4404 SKD12	4659 BA2	A35-590 2231 Z100CDV5	**2260**
A3	...	...	...	...	...
A4	...	...	...	...	...
A5	...	...	...	...	...
A6	...	...	4659 BA6	...	...
A7	...	...	...	...	...
A8	1.2606	G4404 SKD62	...	3432 Z38CDWV5	...
A9	...	...	...	...	...
A10	...	...	...	...	...

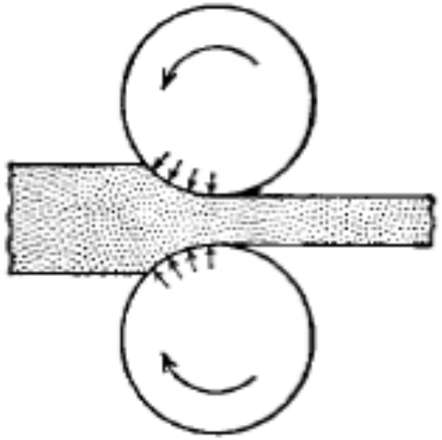
United States (AISI)	West Germany (DIN)[a]	Japan (JIS)[b]	Great Britain (B.S.)[c]	France (AFNOR)[d]	Sweden (SS14)
High-carbon, high-chromium, cold-work steels (ASTM A 681)					
D2	1.2201, 1.2379, 1.2601	G4404 SKD11	4659 (USA D2) 4659 BD2 4659 BD2A	A35-590 2235 Z160CDV12	**2310**
D3	1.2080, 1.2436, 1.2884	G4404 SKD1 G4404 SKD2	4659 BD3	A35-590 2233 Z200C12	...
D4	1.2436, 1.2884	G4404 SKD2	4659 (USA D4)	A35-590 2234 Z200CD12	**2312**
D5	1.2880	...	...	A35-590 2236 Z160CKDV 12.03	...
D7	1.2378	...	...	2237 Z230CVA 12.04	...

United States (AISI)	West Germany (DIN)[a]	Japan (JIS)[b]	Great Britain (B.S.)[c]	France (AFNOR)[d]	Sweden (SS_{14})
Oil-hardening cold-work steels (ASTM A 681)					
O1	1.2510	G4404 SKS21 G4404 SKS3 G4404 SKS93 G4404 SKS94 G4404 SKS95	4659 BO1	A35-590 2212 90 MWCV5	**2140**
O2	1.2842	. . .	4659 (USA O2) 4659 BO2	A35-590 2211 90MV8	**. . .**
O6	1.2206	. . .	. . .	A35-590 2132 130C3	**. . .**
O7	1.2414, 1.2419, 1.2442, 1.2516, 1.2519	G4404 SKS2	. . .	A35-590 2141 105WC13	**. . .**

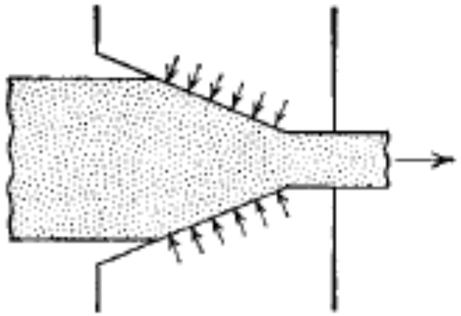
Metalworking Process



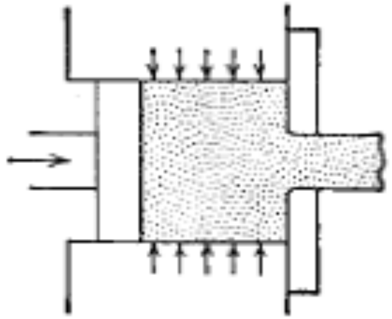
Forging



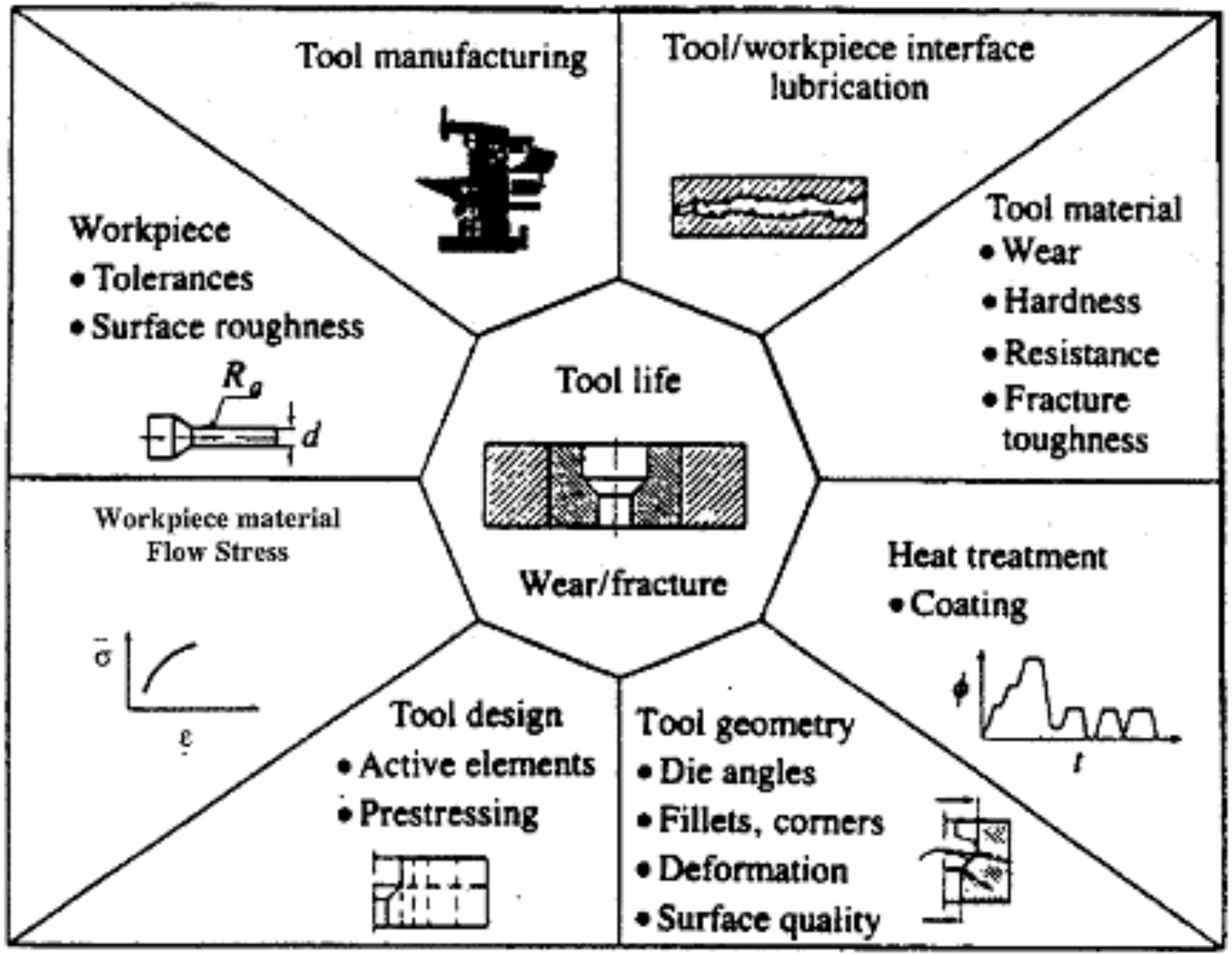
Rolling



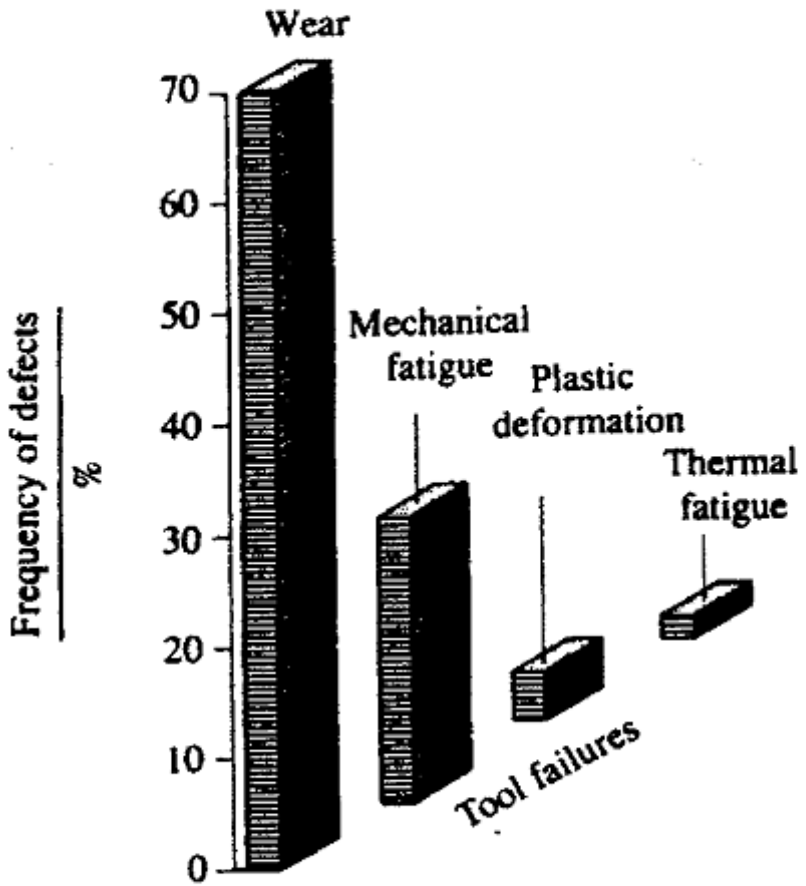
Wire drawing

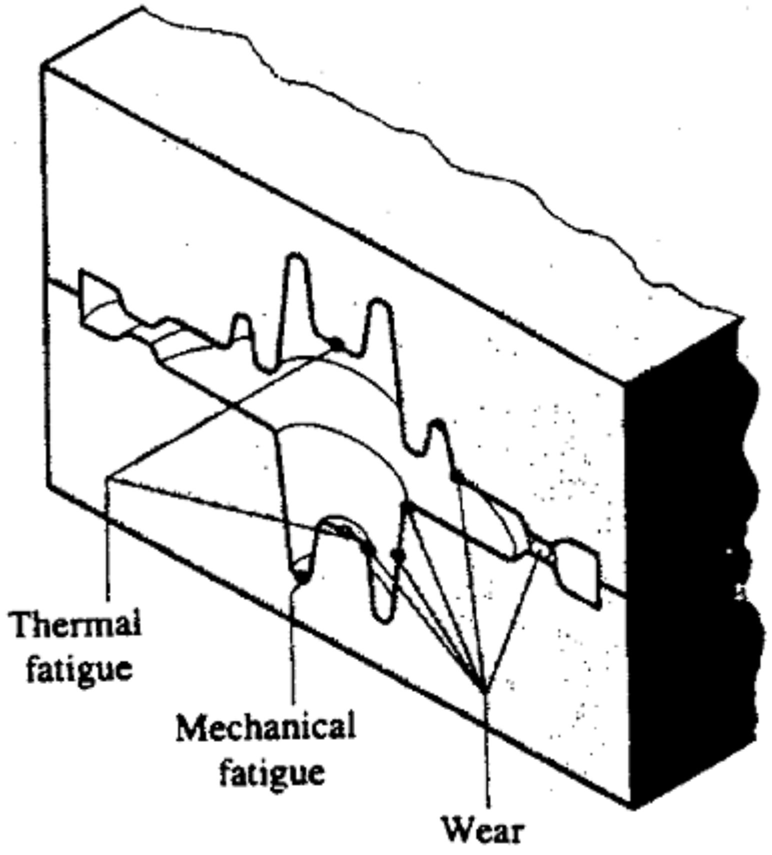


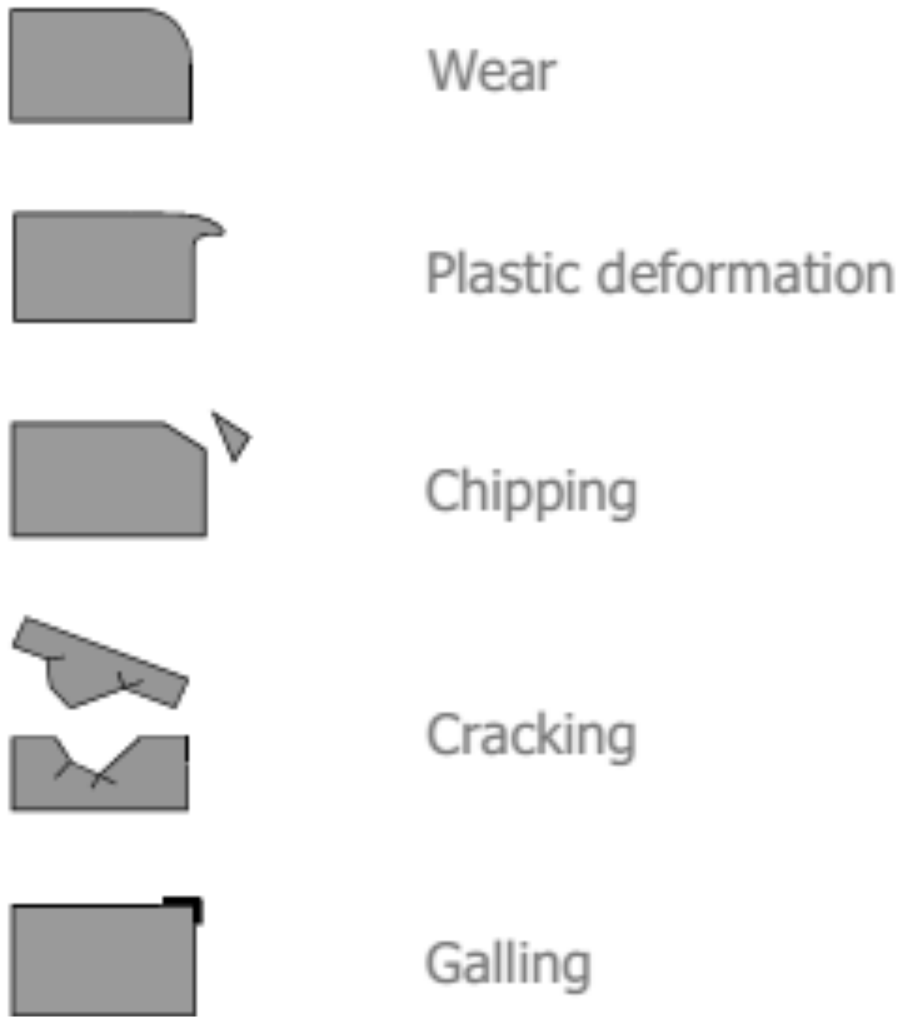
Extrusion

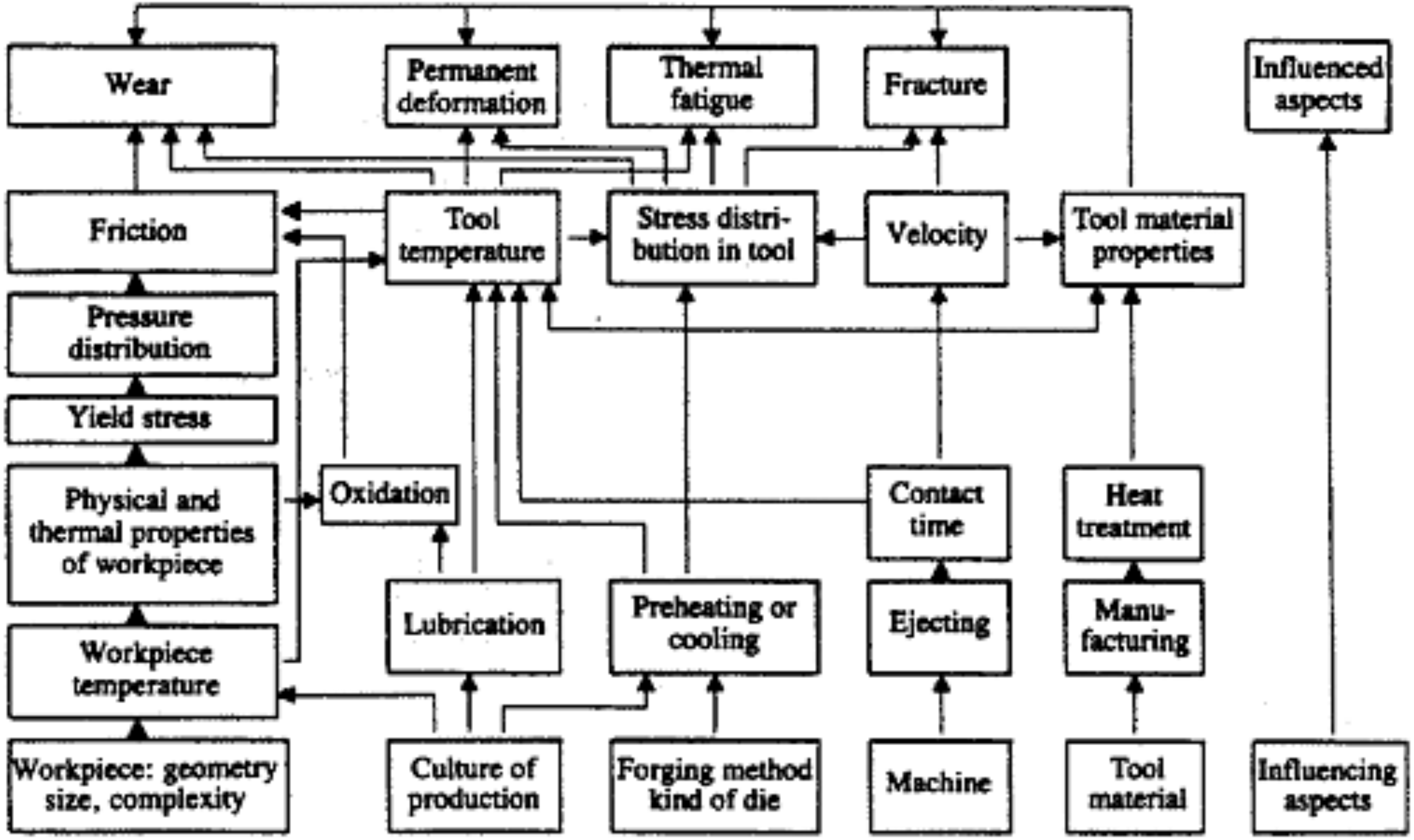


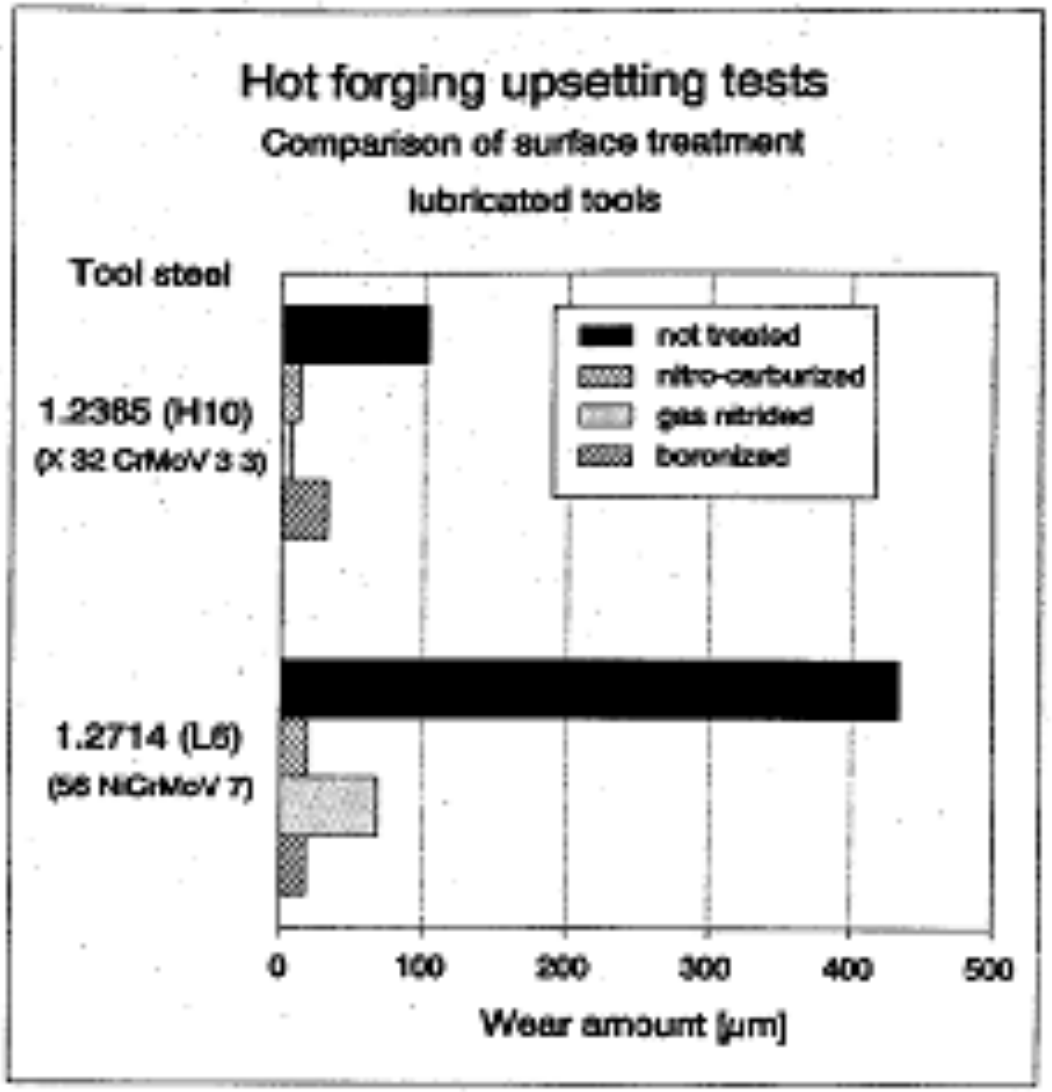
Tool manufacturing
Tool/workpiece interface lubrication
Workpiece
• Tolerances
• Surface roughness
R_a
d
Tool life
Tool material
• Wear
• Hardness
• Resistance
• Fracture toughness
Workpiece material Flow Stress
$\bar{\sigma}$
$\bar{\varepsilon}$
Wear/fracture
Heat treatment
• Coating
ϕ
t
Tool design
• Active elements
• Prestressing
Tool geometry
• Die angles
• Fillets, corners
• Deformation
• Surface quality


Wear
Frequency of defects
%
70
60
50
40
30
20
10
0
Mechanical fatigue
Plastic deformation
Thermal fatigue
Tool failures

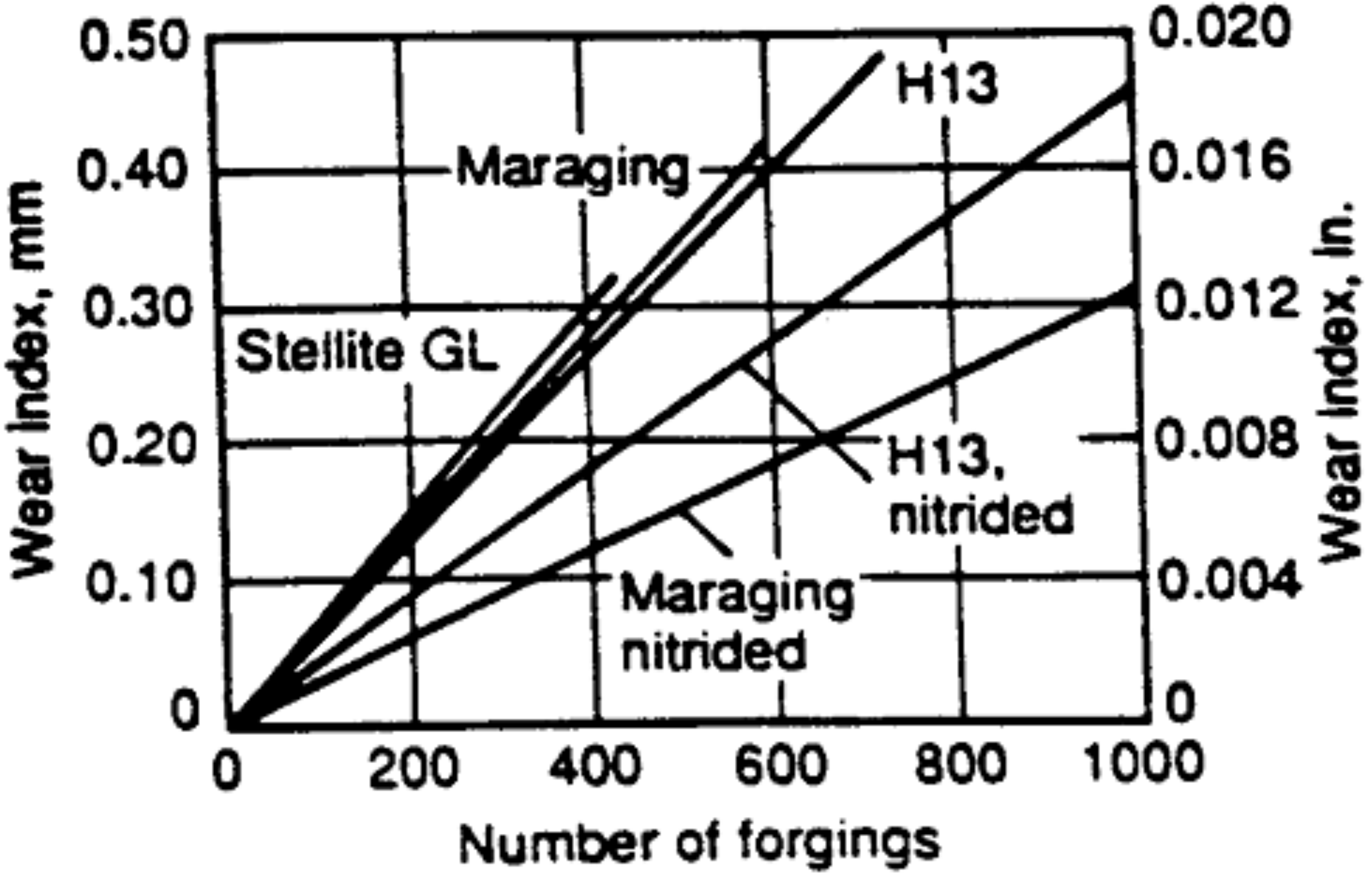

Thermal fatigue
Mechanical fatigue
Wear


Wear
Plastic deformation
Chipping
Cracking
Galling

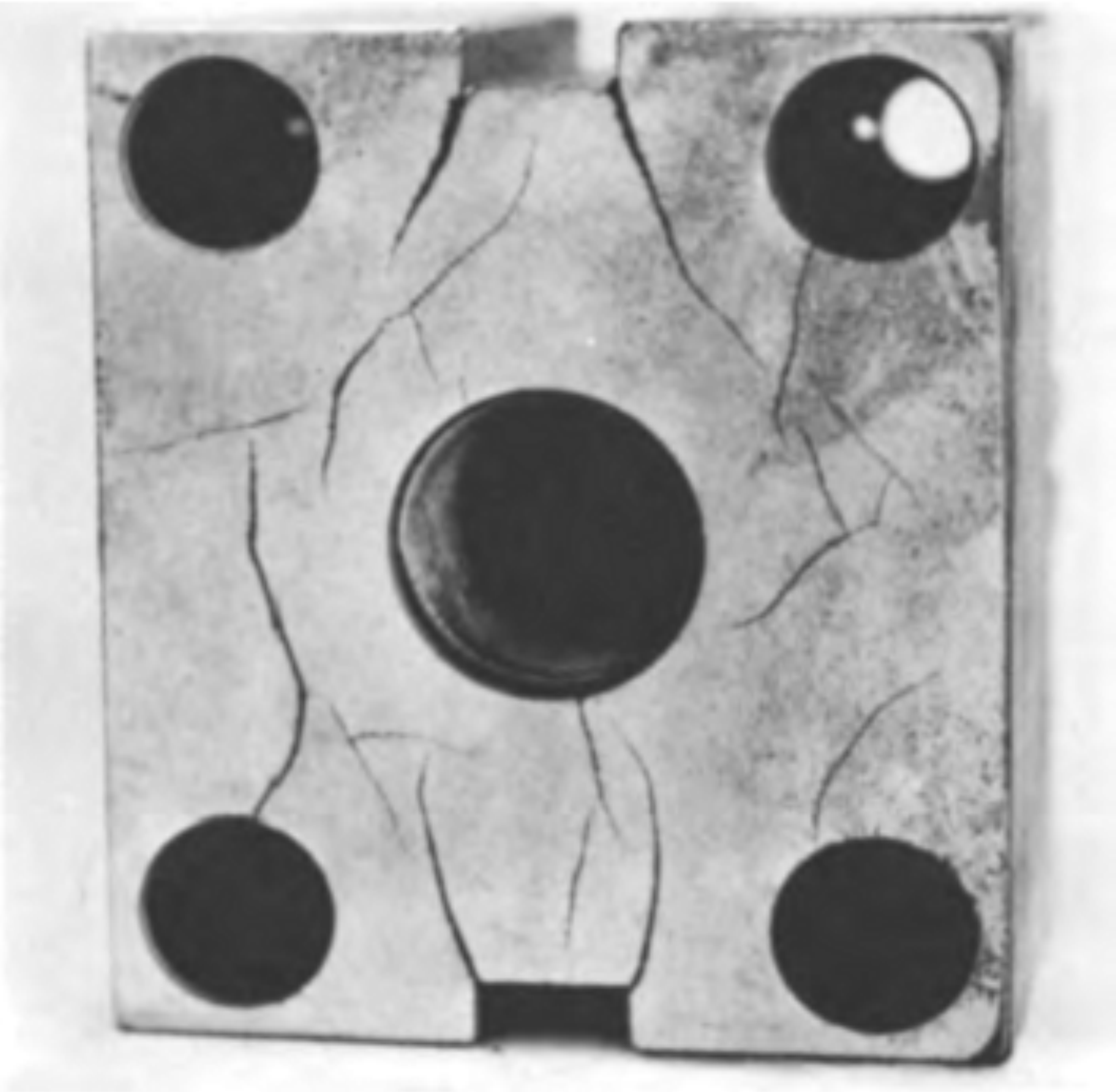
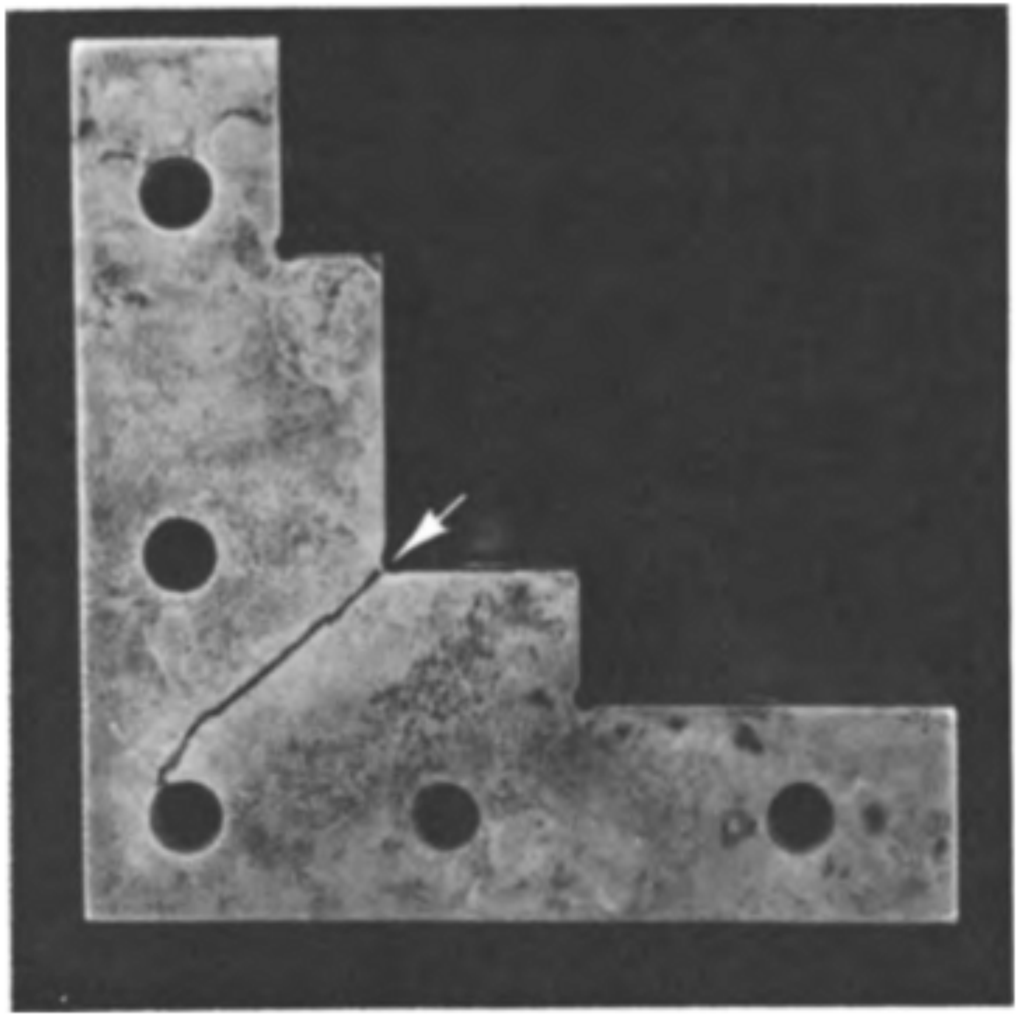

Wear
Permanent deformation
Thermal fatigue
Fracture
Influenced aspects
Friction
Tool temperature
Stress distri-bution in tool
Velocity
Tool material properties
Pressure distribution
Yield stress
Physical and thermal properties of workpiece
Oxidation
Contact time
Heat treatment
Workpiece temperature
Lubrication
Preheating or cooling
Ejecting
Manu-facturing
Workpiece: geometry size, complexity
Culture of production
Forging method kind of die
Machine
Tool material
Influencing aspects

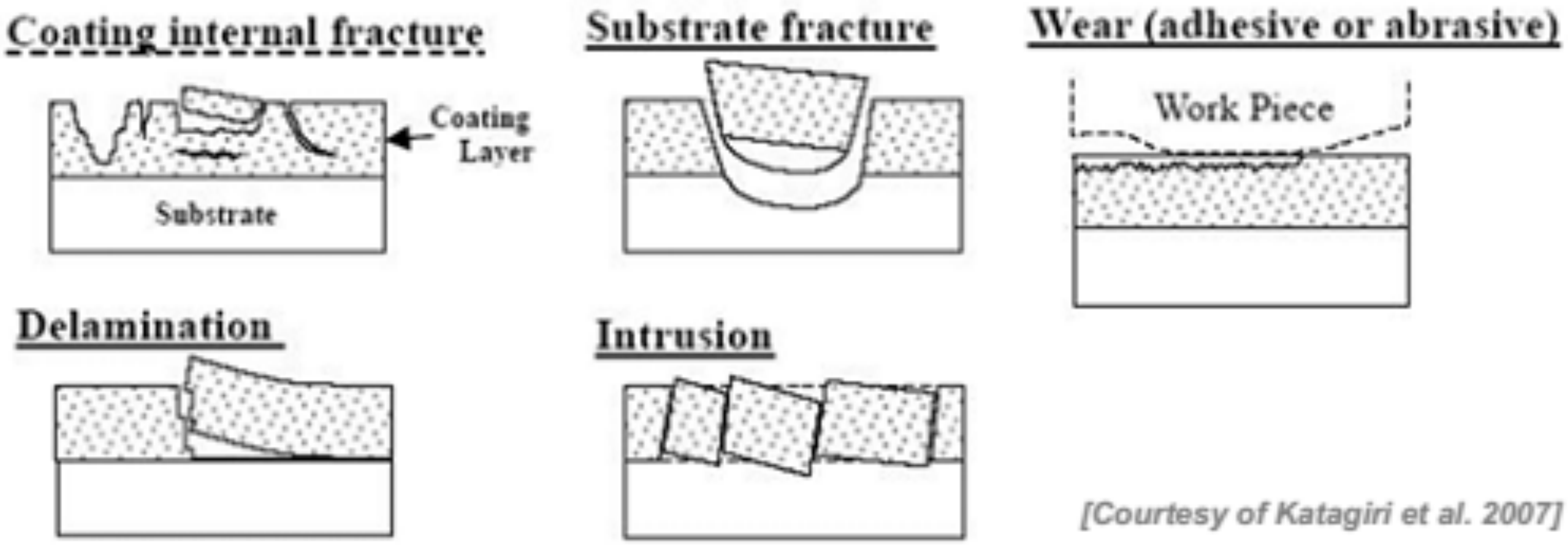


Hot forging upsetting tests
Comparison of surface treatment
lubricated tools
Tool steel
1.2365 (H10)
(X 32 CrMoV 3 3)
1.2714 (L6)
(56 NiCrMoV 7)
not treated
nitro-carburized
gas nitrided
boronized
0
100
200
300
400
500
Wear amount [µm]



0.50
0.40
0.30
0.20
0.10
0
Wear Index, mm
0.020
0.016
0.012
0.008
0.004
0
Wear Index, in.
H13
Maraging
Stellite GL
H13, nitrided
Maraging nitrided
0
200
400
600
800
1000
Number of forgings



[Courtesy of Katagiri et al. 2007]

Chromium Plating

- A thin layer of chromium may be applied to forming and drawing dies in order to increase wear resistance and reduce galling.
- This chromium-plated surface has a very low coefficient of friction with excellent non-galling characteristics.
- The usual practice is to apply a layer of chromium 0.0005 to 0.001 in. (0.013 to 0.025 mm) thick to a very finely ground or polished surface.

Nitriding

- Al Cr Mo V
- Low treatment temperature
- No distortion
- Higher surface hardness
- Good resistance to tempering
- 24-72 hr.
- 500-590 ^{o}C

The following steels can be gas nitrided for specific applications:

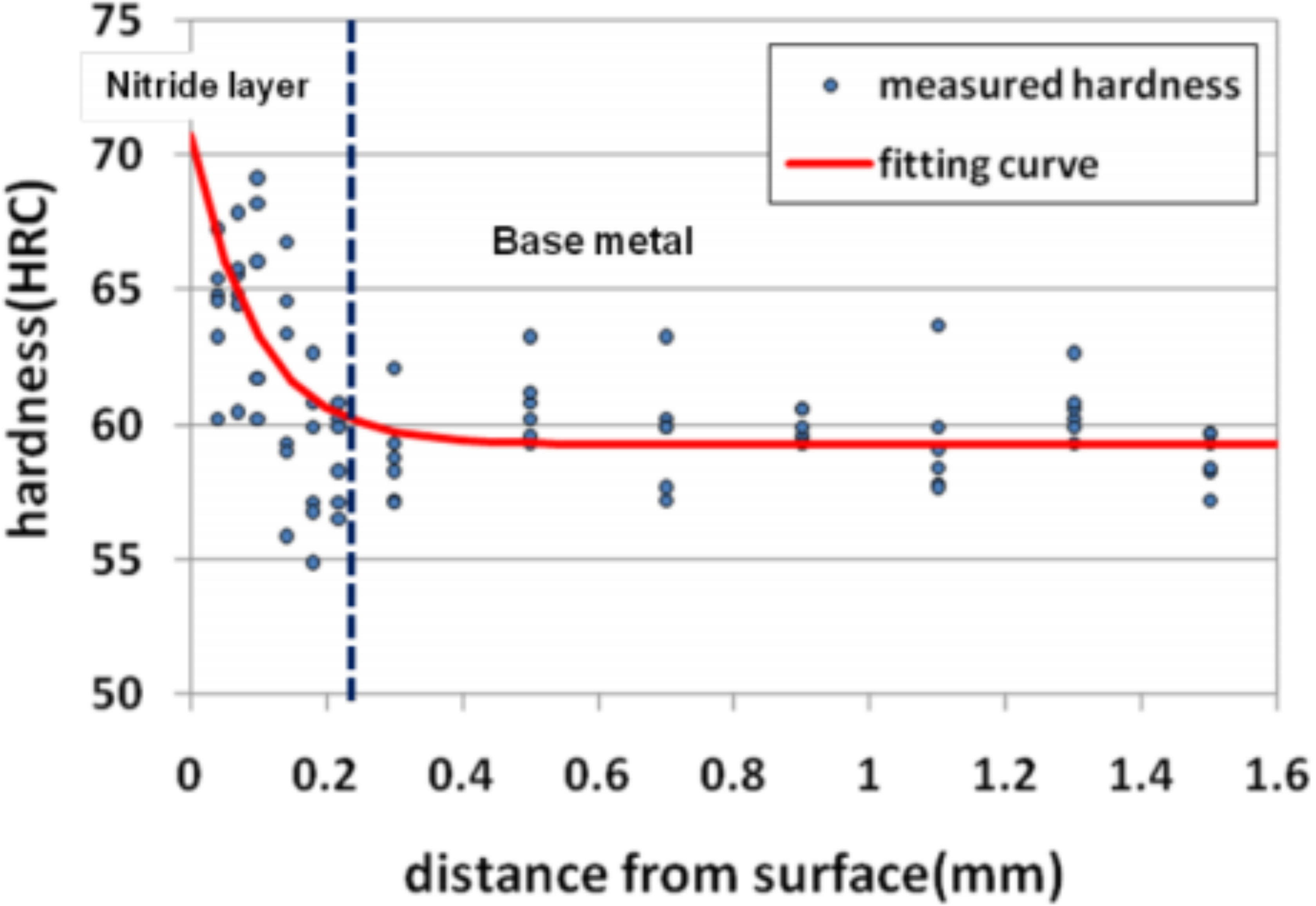
- Aluminum-containing low-alloy steels (Table 1)
- Medium-carbon, chromium-containing low-alloy steels of the 4100, 4300, 5100, 6100, 8600, 8700, and 9800 series
- Hot-work die steels containing 5% chromium such as H11, H12, and H13
- Low-carbon, chromium-containing low-alloy steels of the 3300, 8600, and 9300 series
- Air-hardening tool steels such as A-2, A-6, D-2, D-3, and S-7
- High-speed tool steels such as M-2 and M-4
- Nitronic stainless steels such as 30, 40, 50, and 60
- Ferritic and martensitic stainless steels of the 400 and 500 series
- Austenitic stainless steels of the 200 and 300 series
- Precipitation-hardening stainless steels such as 13-8 PH, 15-5 PH, 17-4 PH, 17-7 PH, A-286, AM350, and AM355

Gas Nitriding

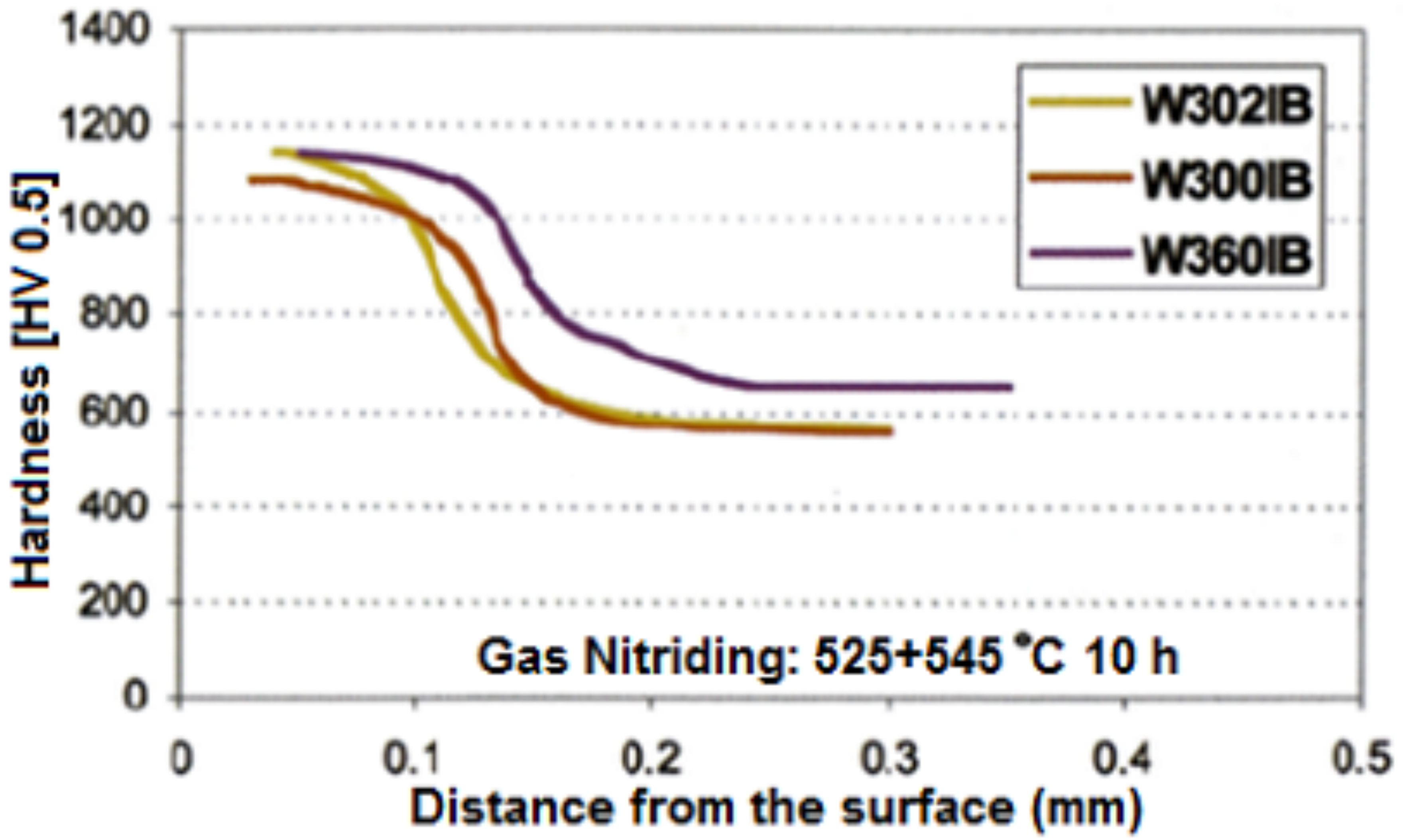
- The use of gas nitriding to produce a hard, wear-resisting case on steels has been commercially practiced for many years.
- This procedure can be used also on some tool steels to improve wear resistance.
- Gas nitriding can be used on tool steels which do not temper back excessively at the nitriding temperature, typically 975° F (524° C).
- This limits gas nitriding largely to the hot-work steels and the high-carbon high-chromium grades.
- Gas nitriding of tool steels requires from 10 to 72 hours. Typical case depths range from 0.002 to 0.018-inch (0.05 to 0.46 mm).

Ion Nitriding

- Uses range from improving the wear resistance of small tool steel die sections to large iron alloy sheet metal drawing punches weighing 10 or more tons.
- Unlike the older gas nitriding process, a *glow discharge* or *ion processing* takes place when a DC voltage is applied between the furnace as the anode and the workpiece as the cathode.
- The furnace atmosphere consists of nitrogen gas under much less than atmospheric pressure.



Nitride layer
Base metal
measured hardness
fitting curve
hardness(HRC)
75
70
65
60
55
50
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
distance from surface(mm)



1400
1200
1000
800
600
400
200
0
Hardness [HV 0.5]
W302IB
W300IB
W360IB
Gas Nitriding: 525+545 °C 10 h
0
0.1
0.2
0.3
0.4
0.5
Distance from the surface (mm)

Titanium Nitride (TiN) and Titanium Carbide (TiC)

- Both of these coatings improve the life of tools by acting as a chemical and thermal barrier to diffusion and fusion.
- The coatings are very thin, typically 0.0001 to 0.0003 in. (0.0025 to 0.0076 mm) in thickness, and quite hard.
- By depositing TiN or TiC onto a steel or carbide tool, the improvement in lubricity causes the tool to resist galling.

Physical Vapor Deposition of Titanium Nitride

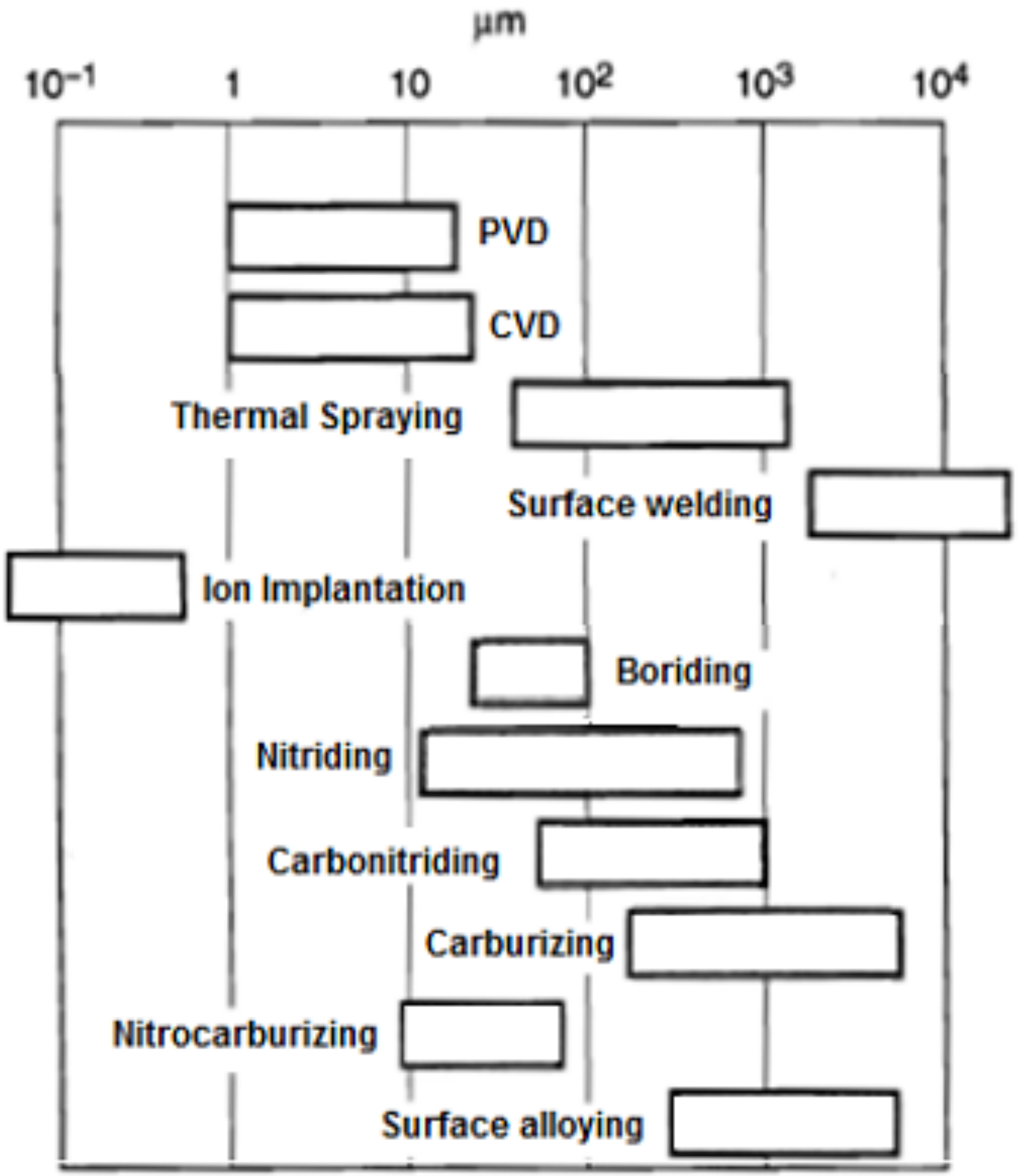
- This coating process is carried out in a high vacuum at temperatures between 400° to 900° F (204° to 482° C).
- Because there is very little distortion or size change on the workpiece, this coating process is frequently used to coat finished punches and buttons whenever rapid wear or galling is found a problem.
- A TiN coating deposited by the PVD process is easily recognized by its gold color.

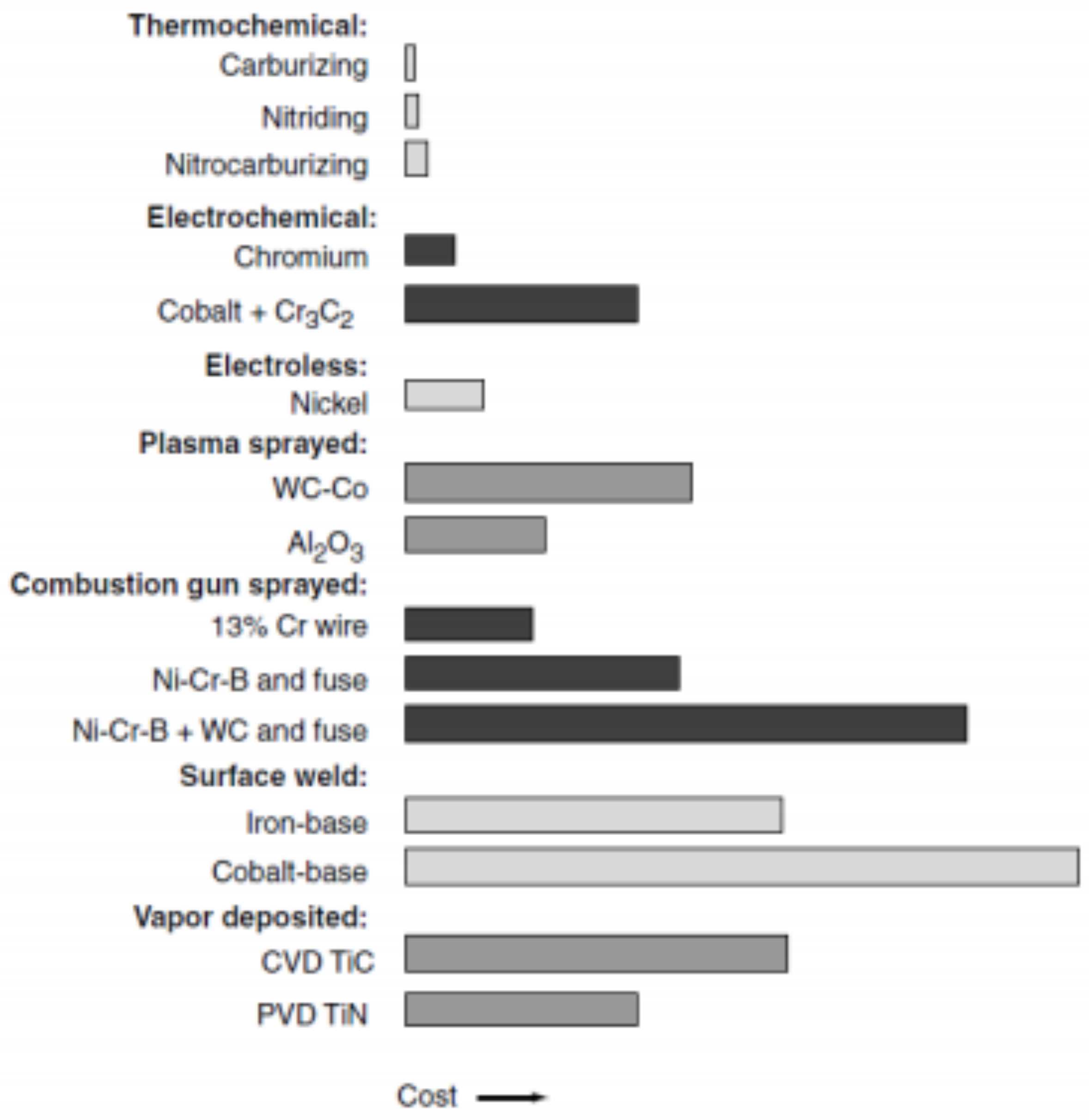
Chemical Vapor Deposition of Titanium Carbide and Nitride

- This coating process is done at much higher temperatures, 1740° to 1920° F (949° to 1049° C) than the PVD process.
- The coating is deposited from a vapor.
- A CVD coating is dull gray in color.
- When a CVD-coated tool is polished, the resultant tool is silver, indistinguishable from the base metal.

Thermal Diffusion (TD)

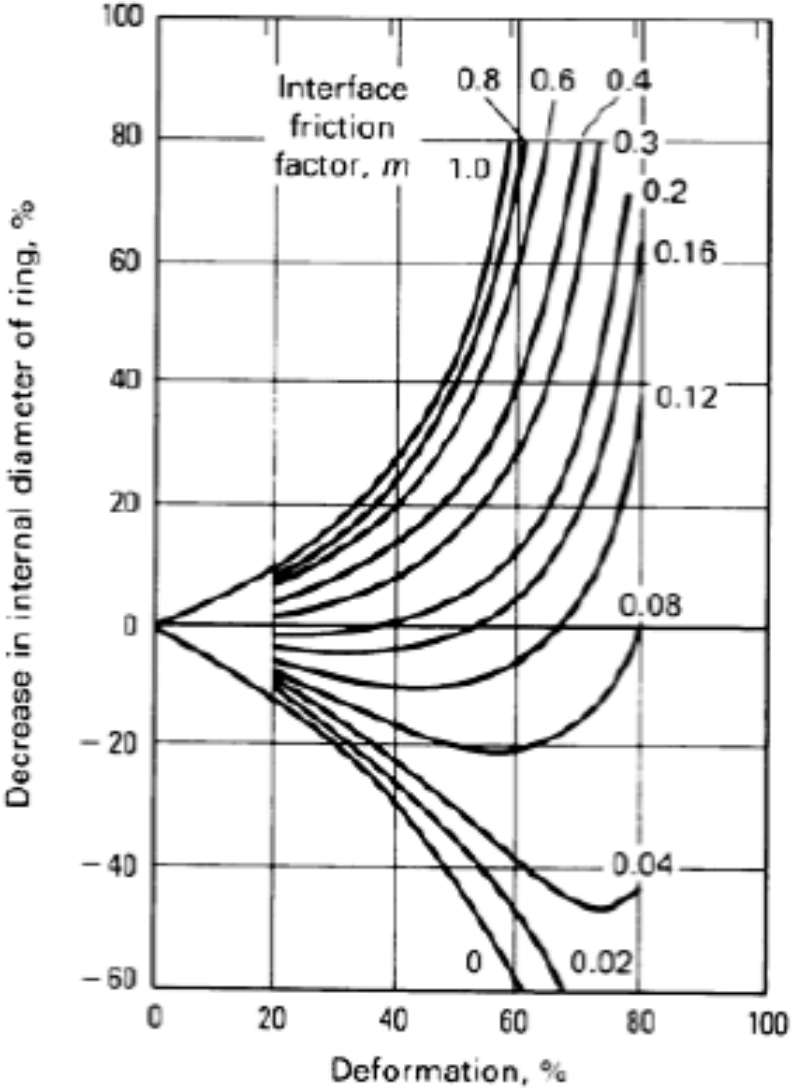
- The TD process is performed by immersing parts in a fused salt bath at temperatures of 1600° to 1900° F (871° to 1039° C) for one to eight hours.
- Carbide constituents dispersed in the salt bath combine with carbon atoms contained in the tooling substrate, which must contain at least 0.3% carbon or greater.
- The carbide layer most commonly produced is vanadium carbide; although, depending on the composition of the salt bath, other carbides can be deposited.
    - niobium carbide, chromium carbide, and a niobium vanadium combination.
- There is a die part size limitation due to limitations on salt bath size, which is a limiting factor on the application of this process.


µm
10⁻¹
1
10
10²
10³
10⁴
PVD
CVD
Thermal Spraying
Surface welding
Ion Implantation
Boriding
Nitriding
Carbonitriding
Carburizing
Nitrocarburizing
Surface alloying


Thermochemical:
Carburizing
Nitriding
Nitrocarburizing
Electrochemical:
Chromium
Cobalt + Cr_3C_2
Electroless:
Nickel
Plasma sprayed:
WC-Co
Al_2O_3
Combustion gun sprayed:
13% Cr wire
Ni-Cr-B and fuse
Ni-Cr-B + WC and fuse
Surface weld:
Iron-base
Cobalt-base
Vapor deposited:
CVD TiC
PVD TiN
Cost

Material	Impact Toughness	Hot Hardness	Resistance to softening at elevated temperature	Thermal checking resistance	Wear resistance	Response to surface engineering
H-13	medium	medium	medium	high	medium	Ion Nitriding, Laser, PFS, PVD, TD-VC
ORVAR Supreme	high	medium	medium	high	medium	Ion Nitriding, Laser, PFS, PVD, TD-VC
QRO Supreme	high	high	high	very high	medium	Ion Nitriding, Laser, PFS, PVD, TD-VC
AerMet 100	very high	low	low	n.a.	medium	Laser, PFS, PVD, TD-VC
Matrix II	medium	very high	very high	very high	medium	Ion Nitriding, Laser, PFS, PVD, TD-VC
D2	low				high	Ion Nitriding, PFS, PVD, TD-VC

Ring Compression Test



Interface friction factor, m
1.0
0.8
0.6
0.4
0.3
0.2
0.16
0.12
0.08
0.04
0.02
0
Decrease in internal diameter of ring, %
Deformation, %
100
80
60
40
20
0
− 20
− 40
− 60
0
20
40
60
80
100

หน้าที่ของ Lubricant

- to control friction at the workpiece/tool interface,
- to cool down tool surfaces to avoid overheating and a drop of tool hardness,
- to protect workpiece and tool surfaces.

Metal Forming and Lubrication ☆

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Water based lubricants

- such as emulsions of oil in water used in cold rolling or dispersions of graphite particles in water used in hot forging.
- In both cases, the water acts as a carrier to bring the active compounds of the lubricant into the contact zone.
- In hot forming, water based lubricants are sprayed on tools to cool down their surfaces and avoid overheating.

Oils

- Oils are widely used as lubricants in metal forming.
- Whatever their origin (mineral coming from the refining of hydrocarbons, natural coming from vegetable, or animal sources, or synthetic created in a lab), their viscosity and the way oils react with metallic surfaces allow a lubricant film to be preserved between workpiece and tool surfaces, avoiding direct metal-to-metal contact to occur.
- Nonetheless oils are rarely used pure. Additives are generally added to the oils to limit the risk of a lubricant film breakdown.
- Main additives are boundary additives used to limit wear, such as ZDDP, and Extreme Pressure (EP) additives commonly involved for applications at high temperatures where boundary additives are ineffective. Typical EP additives are sulfonated, chlorinated, or phosphorous fatty oils or esters.
- Oils may contain fatty acids that react with the metal oxides on the workpiece surface. The reaction lead to a solid metal soap chemically bonded to the surface which reduces friction and protects tool and workpiece surfaces. These lubricants are encountered either in cold or hot forming.

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Layer lattice compounds

- such as graphite, Hexagonal boron nitride (hBN) or molybdenum disulfide MoS2.
- Their layer structure contributes to the weak shear strength of the lubricant, but the efficiency of the lubricant may be very sensitive to
  particle size (Podgornik et al., 2015; Daouben et al., 2008)

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Coatings

- Coatings are solid lubricants without chemical reaction on the surface they are deposited on.
- This class of lubricants includes polymer coatings (such as PTFE) and mineral salt coatings (such as Borax, calcium, or sodium based soaps deposited on non-reactive pre-coatings).
- Coatings are applied on workpiece surface mainly for stationary cold forming processes (such as wire drawing).

Conversion coatings

- These coatings involve a chemical reaction of the workpiece surface layers.
- Conversion coatings act as binders between the workpiece surface and a solid lubricant (soap) (Bricout et al., 1995).
- This class of lubricant includes the zinc phosphate coatings.
- They are widely used in cold forming for their ability to undergo large strain and surface enlargement

Metal Forming and Lubrication ☆

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Type of Forging Die Lubricants

Lubricant	Advantages	Disadvantages
Furnace oil	• Least expensive • No purchase hassles	• Carcinogenic • Low die life • Dirties the die and surrounding • Highly polluting
Special oil + graphite	• Improves die life	• Some amount of gentle smoke is emitted
Only oil, without graphite.	• Suitable for brass	• Not suitable for steel
Water + common salt	• Apparently economical	• Corrosive

Lubricant Choices and Forging Cost

S.P. Shenoy

Type of Forging Die Lubricants

Water + saw dust	• Economical	• Explosion due to rapid phase change • Unsafe
Water + graphite	• Improves die life • No smoke • Eco-friendly	• Graphite particles fly off and damage the electrical systems • Graphite particles acc mulate on shop floor. • Risk of slipping
Water + soluble lubricant	• Easy to use •No particulate settling • Improved die life • Improved productivity • Non-polluting • Most eco-friendly	• Not adequate for very large forgings

Lubricant Choices and Forging Cost

S.P. Shenoy