THE MECHANICAL PROPERTIES OF MATERIALS CURRENTLY USED IN IMPLANTS

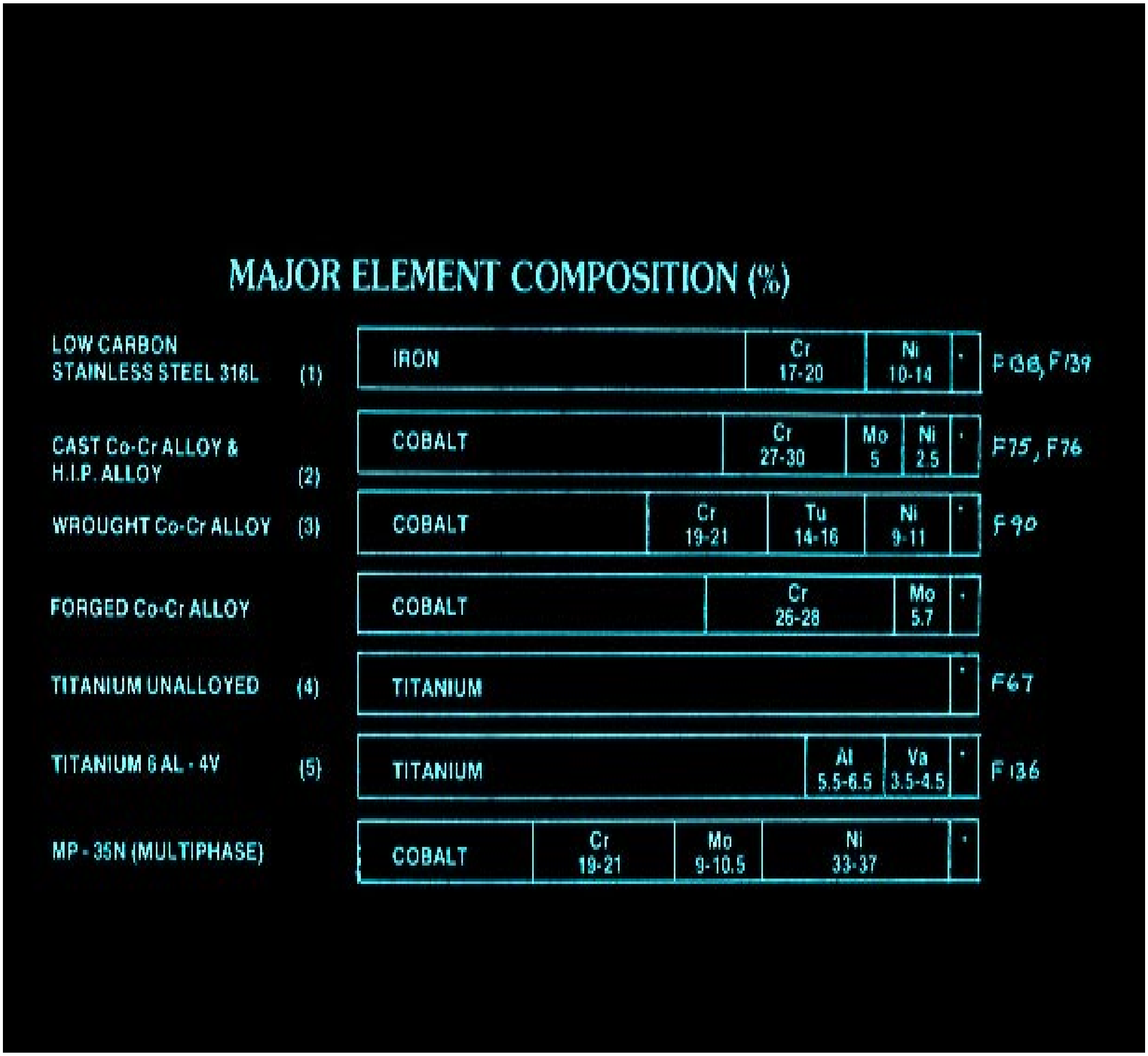
Material	Modulus of Elasticity			Yield Strength (0.2% offset for metals)			Elongation to failure	Fatigue Limit			Sources of Information*
	N/mm^2	kgf/cm^2	lbf/in^2	N/mm^2	kgf/cm^2	lbf/in^2	(percent)	N/mm^2	kgf/cm^2	lbf/in^2	
cast Co-Cr-Mo alloy	0.21×10^6	2.2×10^6	31×10^6	448	4,570	65,000	8	310	3,164	45,000 (in air)	1,2
316-L annealed stainless steel	0.19×10^6	2.0×10^6	28×10^6	207	2,109	30,000	40	—	—	—	1,3
316-L stainless steel cold worked	0.20×10^6	2.1×10^6	30×10^6	690	7,031	100,000	12	345	3,515	50,000 (in air)	1,3
Titanium (pure)	0.10×10^6	1.1×10^6	15×10^6	483	4,922	70,000	15	262	2,672	38,000 (in saline)	4,5
Ti-6Al-4V	0.11×10^6	1.1×10^6	16×10^6	793	8,085	115,000	10	414	4,219	60,000 (in saline)	4,6
ultra-high molecular weight polyethylene	1.4×10^3	14.1×10^3	200×10^3	21	211	3,000	200-400	11	112	1,600	7,8
polymethyl methacrylate (solid)	2.8×10^3	28.1×10^3	400×10^3	55	562	8,000	2	48	492	7,000	7,8
silicon rubber (Silastic HV3602)	0.54-2.0	5.55-20.4	79-290	8.3	84	1,200	300	—	—	—	9
bone	0.01×10^6	0.11×10^6	1.5×10^6	138	1,406	20,000	6.25	34	352	5,000	10,11
acrylic cement (Simplex P)	2.8×10^3	28.1×10^3	400×10^3	13.2	135	1,914	.25	—	—	—	12,13,14

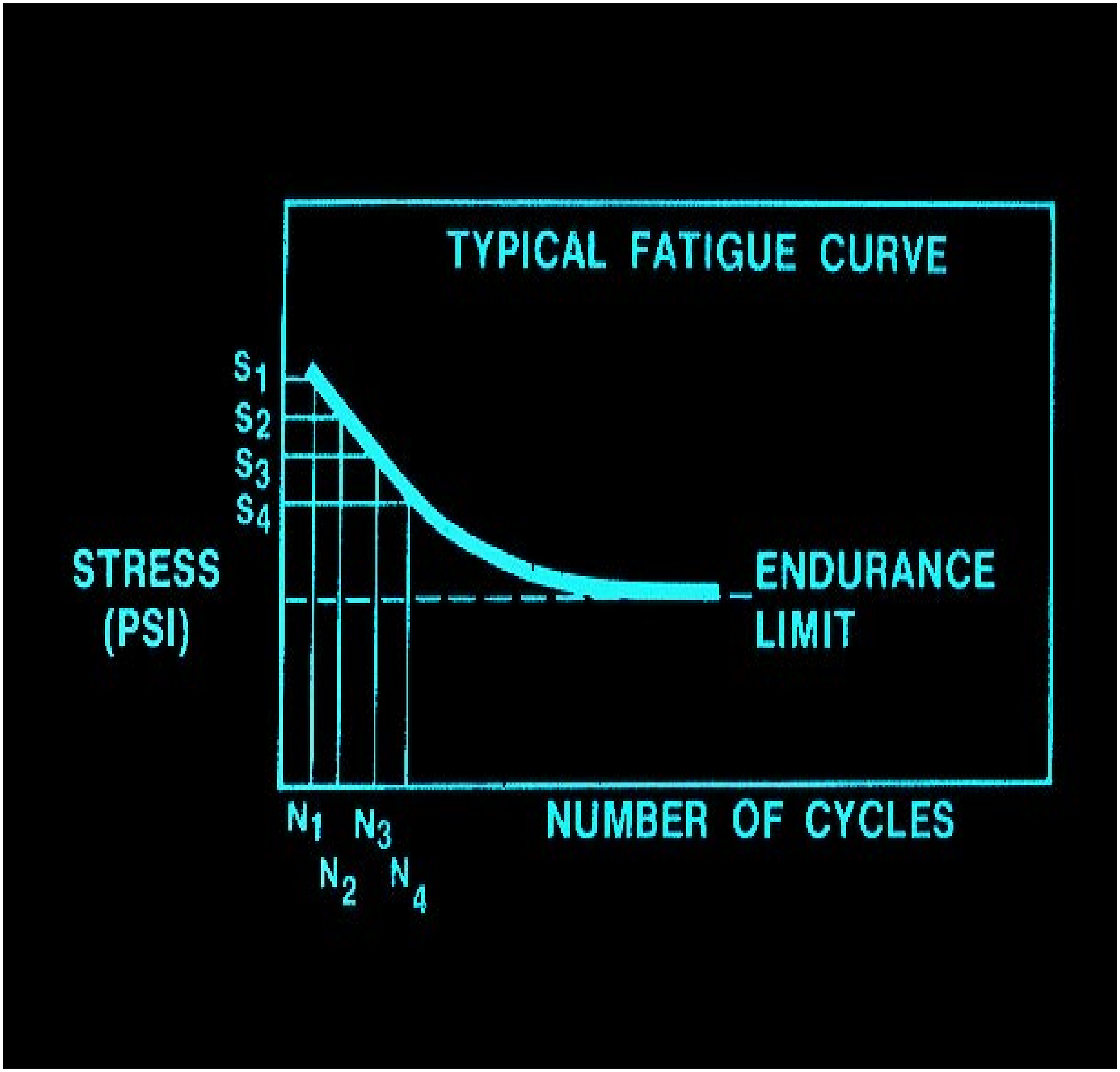
*From 1. Weinman, 1968; 2. A.S.T.M. F 75-67; 3. A.S.T.M. F 56-71; 4. McMaster, 1970; 5. A.S.T.M., F 67-66; 6. A.S.T.M., F 136-70; 7. Several sources; 8. Materials in Design Engineering; 9. Author's tests; 10. See Chapter 3; 11. Burstein et al. 1972; 12. Swanson et al. 1971, King and Evans, 1967; 13. Weinstein et al. 1974; 14. Lautenschlager et al. 1974

Yield and fatigue strength of different alloys proposed for use in hip prostheses (7,10)

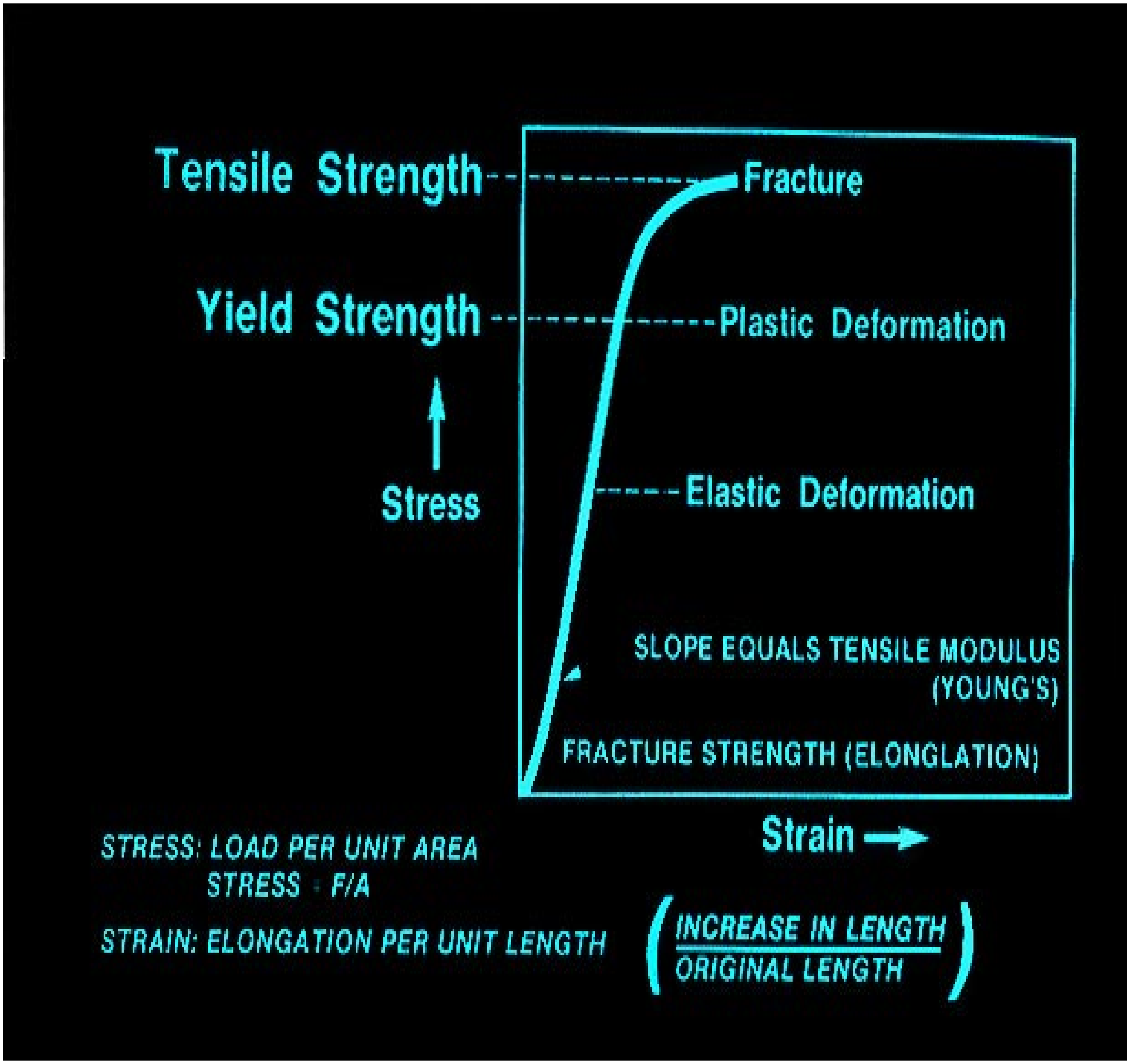
Alloy type	Yield strength $\sigma_{0.2}$ N/mm^2	PSI	Kp/mm^2	Fatigue strength σ_{bw} N/mm^2	PSI	Kp mm^2
CoCrMo	441	63990	45	196	28440	20
CoNiCrMo	637	92430	65	592	76790	54
FeCrNiMo	284	41240	29	245	35550	25
TiAlV	794	115180	81	392	56880	40

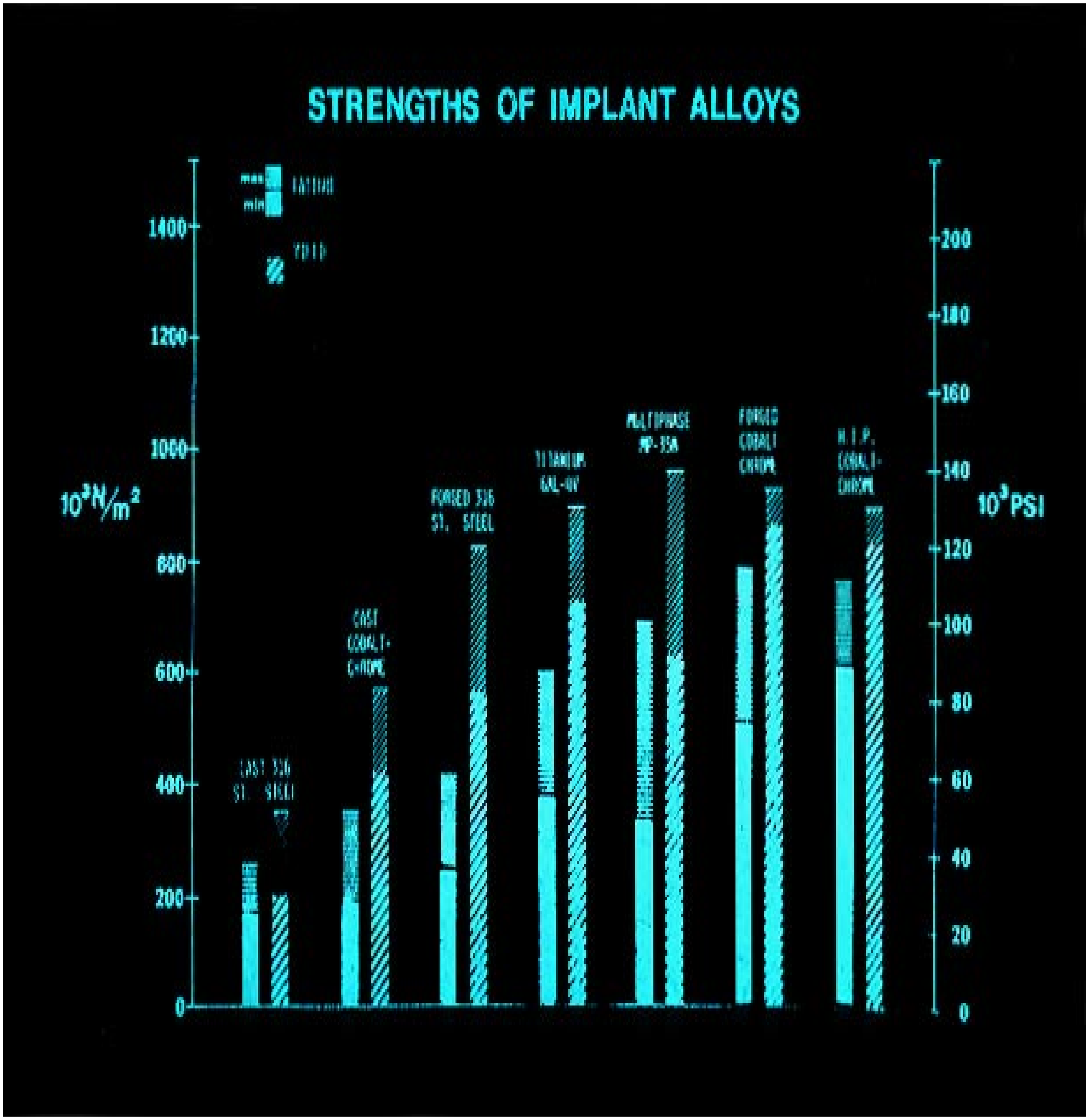
	Toughness %	Hardness V.P.N.
CoCrMo	8	300
CoNiCrMo	35	300
FeCrNiMo	63	165
TiAlV	10	300


MAJOR ELEMENT COMPOSITION (%)
LOW CARBON STAINLESS STEEL 316L (1)
IRON
Cr 17-20
Ni 10-14
*
F 138, F 139
CAST Co-Cr ALLOY & H.I.P. ALLOY (2)
COBALT
Cr 27-30
Mo 5
Ni 2.5
*
F75, F76
WROUGHT Co-Cr ALLOY (3)
COBALT
Cr 19-21
Tu 14-16
Ni 9-11
*
F 90
FORGED Co-Cr ALLOY
COBALT
Cr 26-28
Mo 5.7
*
TITANIUM UNALLOYED (4)
TITANIUM
*
F67
TITANIUM 6 AL - 4V (5)
TITANIUM
Al 5.5-6.5
Va 3.5-4.5
*
F 136
MP - 35N (MULTIPHASE)
COBALT
Cr 19-21
Mo 9-10.5
Ni 33-37
*



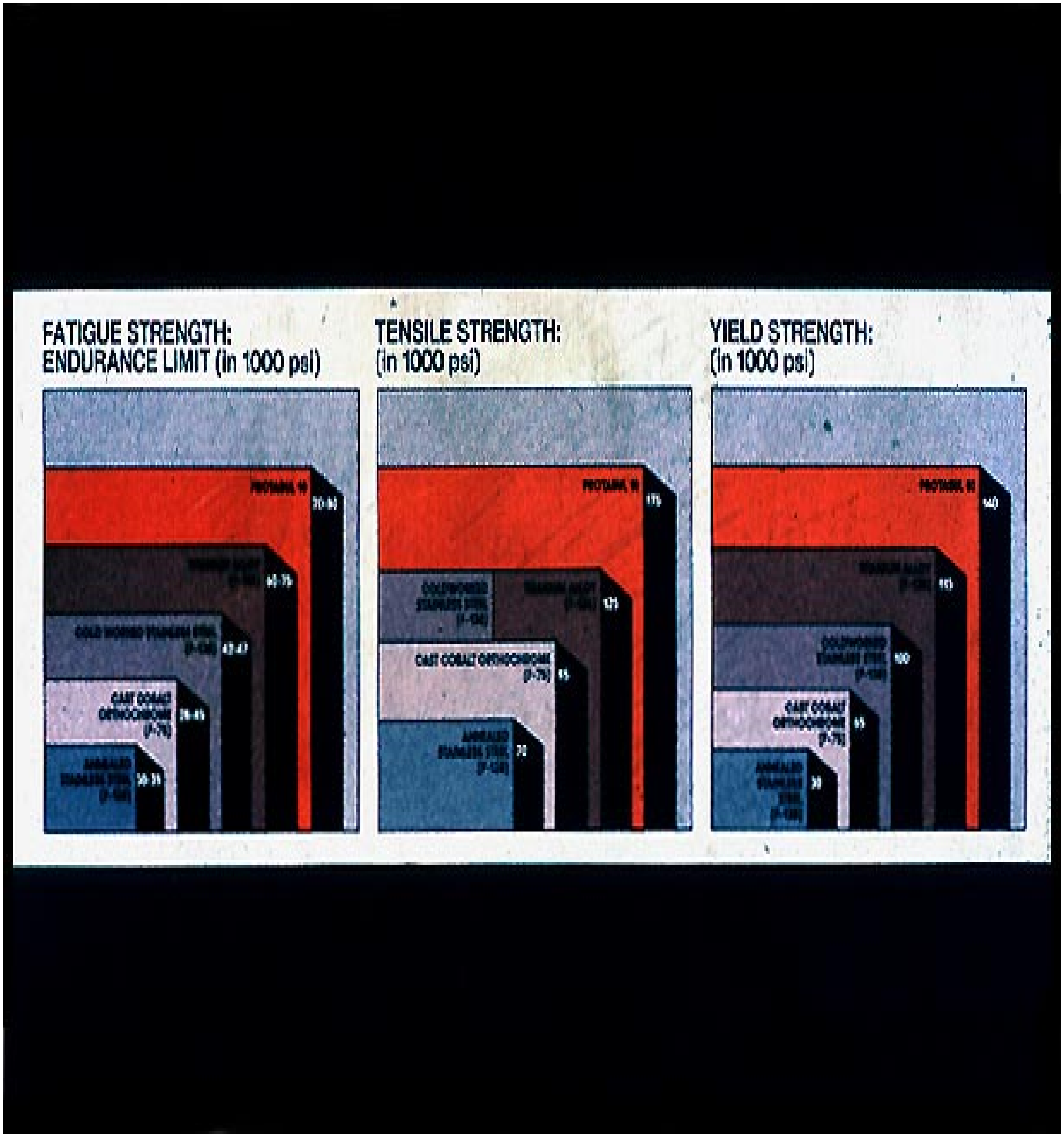
TYPICAL FATIGUE CURVE
S1
S2
S3
S4
STRESS (PSI)
ENDURANCE LIMIT
N1
N2
N3
N4
NUMBER OF CYCLES


Tensile Strength
Fracture
Yield Strength
Plastic Deformation
Stress
Elastic Deformation
SLOPE EQUALS TENSILE MODULUS
(YOUNG'S)
FRACTURE STRENGTH (ELONGLATION)
Strain
STRESS: LOAD PER UNIT AREA
STRESS = F/A
STRAIN: ELONGATION PER UNIT LENGTH
INCREASE IN LENGTH
ORIGINAL LENGTH


STRENGTHS OF IMPLANT ALLOYS
max
min
$10^3 N/m^2$
1400
1200
1000
800
600
400
200
0
10^3 PSI
200
180
160
140
120
100
80
60
40
20
0

TYPICAL MECHANICAL PROPERTIES OF COMMONLY USED ORTHOPAEDIC ALLOYS AND MICRO-GRAIN ZIMALOY

Mechanical Property	ASTM F75 Requirements	Cast Co-Cr-Mo	316L Stainless Steel (cold worked)	Ti-6Al-4V (TIVANIUM)	MP35N (cold worked) PROTASUL-10	Forged VITALLIUM FHS	MICRO-GRAIN ZIMALOY
Ultimate Tensile Strength	95,000 psi min.	105,000	140,000	140,000	175,000	180,000	188,000
Yield Strength	65,000 psi min.	75,000	110,000	130,000	140,000	130,000	133,000
Elongation	8% min.	8%	22%	10%	25%	15%	14%
Reduction of Area	8% min.	8%	55%	25%	65%		16%


FATIGUE STRENGTH:
ENDURANCE LIMIT (in 1000 psi)
TENSILE STRENGTH:
(in 1000 psi)
YIELD STRENGTH:
(in 1000 psi)

100X

Figure 4. Microstructure of investment cast Co-Cr-Mo alloy.

100X

Figure 5. Microstructure of MICRO-GRAIN ZIMALOY.