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TITLE

CURRENT WELDING CONSUMABLES RESEARCH IN THE U.S. NAVY

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CURRENT WELDING CONSUMABLES RESEARCH IN THE U.S. NAVY

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presented by P.W. Holsberg

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ABSTRACT

One of the thrusts of U.S. Navy research is directed toward providing new and advanced material systems with improved properties, and developing methods and materials to construct current and future generation naval vessels more economically. It focuses on materials of construction, fabrication methods and consumables, and methods to ensure and enhance structural integrity. One specific area in this thrust is that of welding the Navy's high strength steels. Toward this end, work is being conducted on a number of topics pertaining to welding Navy steels with yield strengths exceeding 100 ksi.

Four tasks are discussed in this presentation. HSLA-100 Welding Consumables Development addresses evaluation of experimental compositions, data analysis, and identification of optimum compositions. Low-Carbon Bainitic Weld Metals discusses the effects of alloying on weld metal strength and cooling rate sensitivity, and the effect of titanium-bearing inclusions on weld toughness. Weldability Methodology addresses transformation expansion, Weldability tests, diffusible hydrogen, and cracking models. Welding Fluxes discusses determination of flux composition and correlations with weld performance. Future research for each task is also described.

Paper to be presented at OMAE-93, Glasgow, Scotland, June, 1993

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NAVAL APPLICATIONS OF MATERIALS TECHNOLOGY
FMO, Halifax, N.S.
28 April 1993

WELDING CONSUMABLES
THRUST AREAS

* GMAW Filler Metals for HSLA-100
* Low-Carbon Bainitic Filler Metals
* Weldability Methodology
* Welding Fluxes

HSLA-100 CONSUMABLE WELDMENTS
WELDING VARIABLES

Single V, 60 degree included angle

1/2 inch root, 1/2 inch backing bar

Flat position

GMAW with Ar-5%CO2 gas (C-5)

Nominally 50 KJ/in

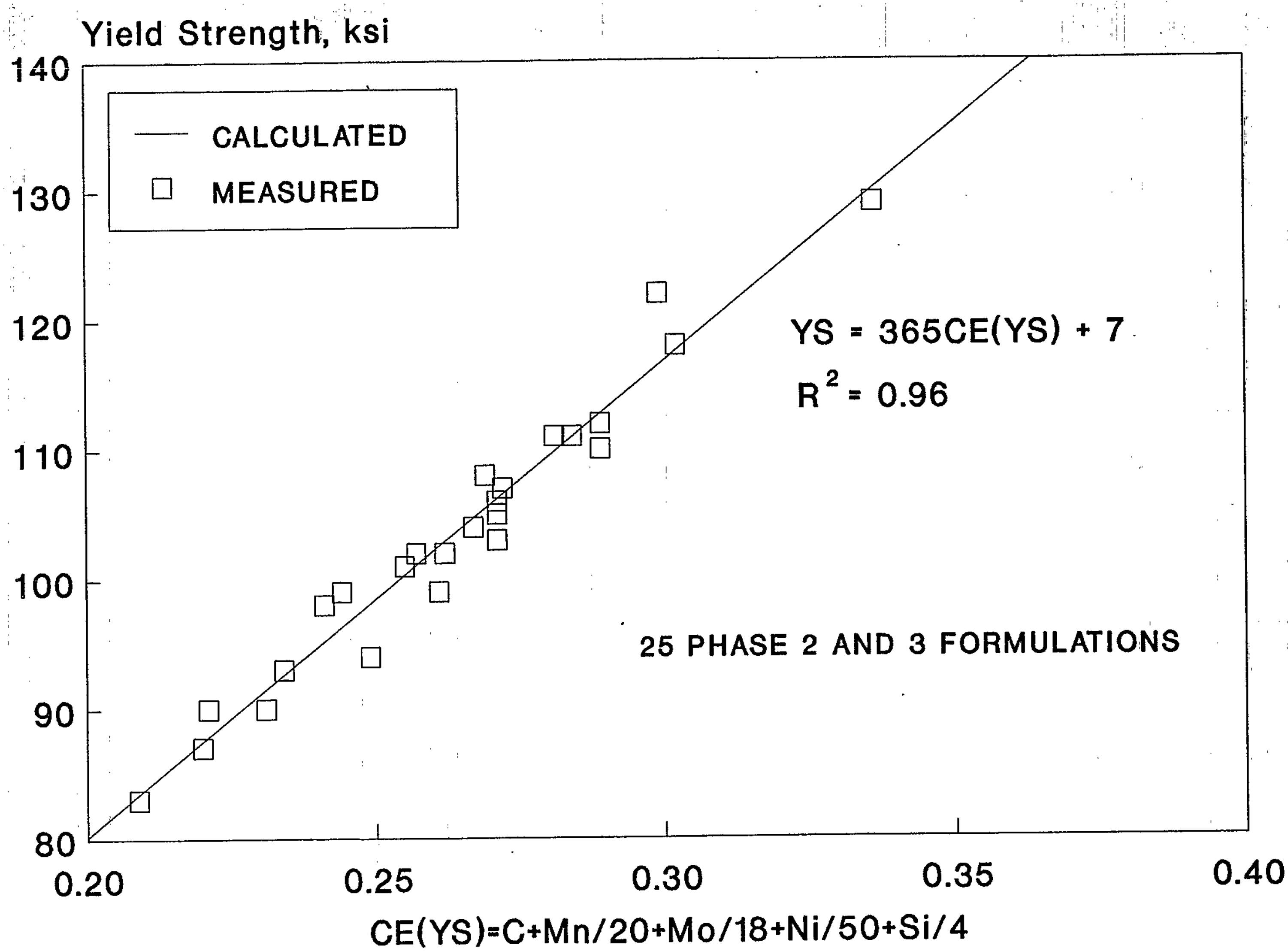
Preheat/interpass 225-275F

Weld metal compositions and mechanical properties from Phase 1.

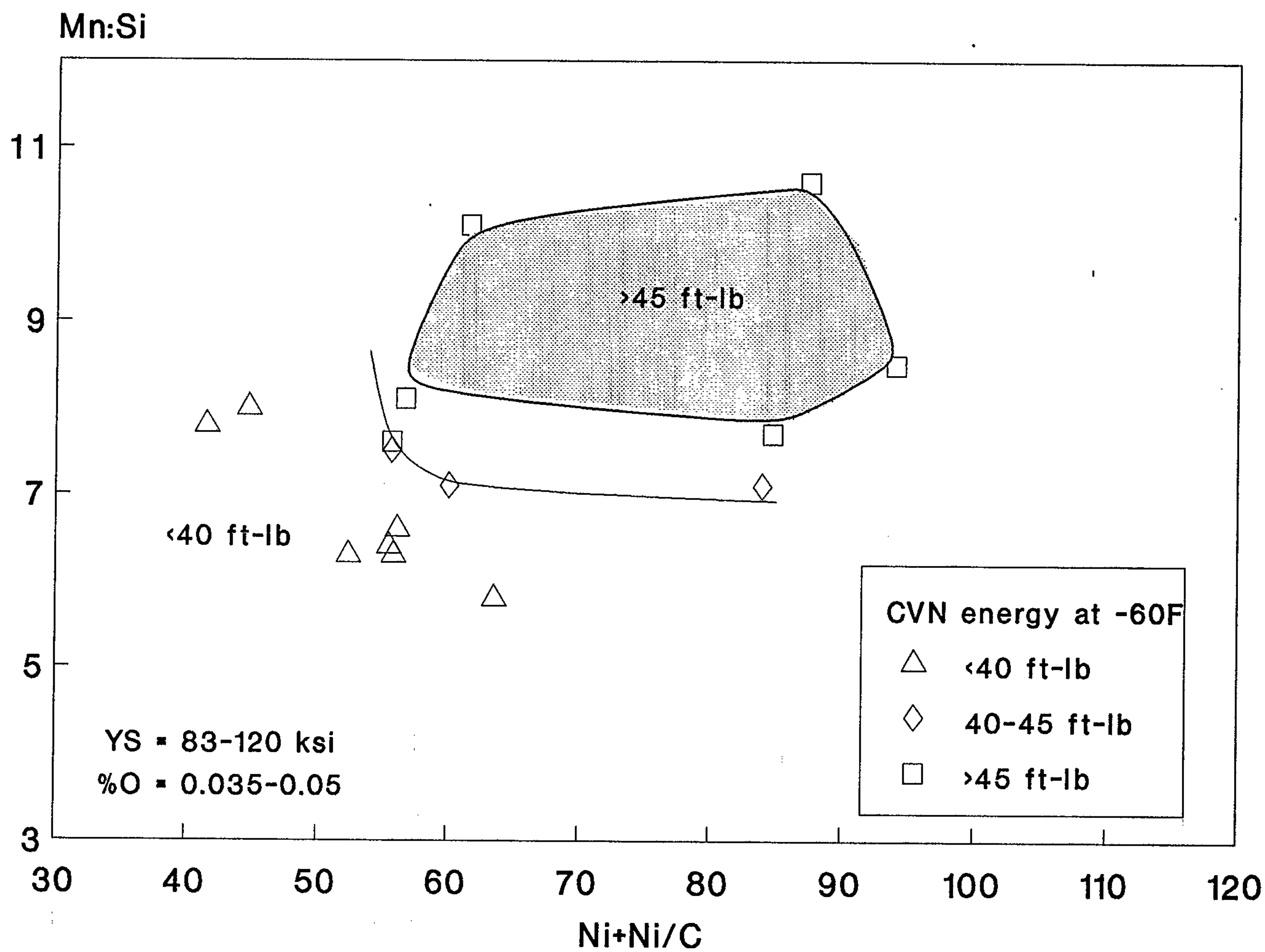
Formulation	C	Ni	Mo	Ti	Mn	Si	O	N	Yield Strength (ksi)	CVN at 0°F (ft-lb)	CVN at -60°F (ft-lb)
1	0.040	2.18	0.42	0.011	1.53	0.19	0.041	0.014	90	88	50
2	0.036	2.14	0.44	0.018	1.41	0.14	0.041	0.010	83	57	45
3	0.040	2.31	0.64	0.012	1.49	0.21	0.043	0.008	94	63	41
4	0.035	2.20	0.64	0.017	1.42	0.14	0.068	0.013	90	66	34
5	0.040	3.26	0.44	0.011	1.54	0.20	0.042	0.008	102	65	51
6	0.037	3.12	0.45	0.017	1.49	0.14	0.041	0.012	93	79	47
7	0.040	3.23	0.63	0.011	1.50	0.21	0.050	0.011	104	69	43
8	0.035	3.18	0.63	0.022	1.53	0.18	0.042	0.013	101	69	49
9	0.050	2.13	0.44	0.012	1.52	0.19	0.041	0.008	98	55	33
10	0.059	2.25	0.46	0.013	1.36	0.09	0.053	0.011	87	50	29
11	0.060	2.35	0.65	0.012	1.55	0.20	0.042	0.007	105	45	17
12	0.060	2.21	0.65	0.023	1.53	0.18	0.033	0.011	102	67	40
13	0.060	3.15	0.44	0.014	1.50	0.20	0.041	0.009	107	55	43
14	0.060	3.12	0.45	0.022	1.57	0.18	0.029	0.010	103	62	54
15	0.060	3.15	0.63	0.014	1.52	0.20	0.041	0.008	111	64	53
16	0.066	3.11	0.63	0.018	1.40	0.15	0.034	0.010	106	60	50
Target Properties									102-122	60 min	45 min

Weld metal compositions and mechanical properties from Phase 2.

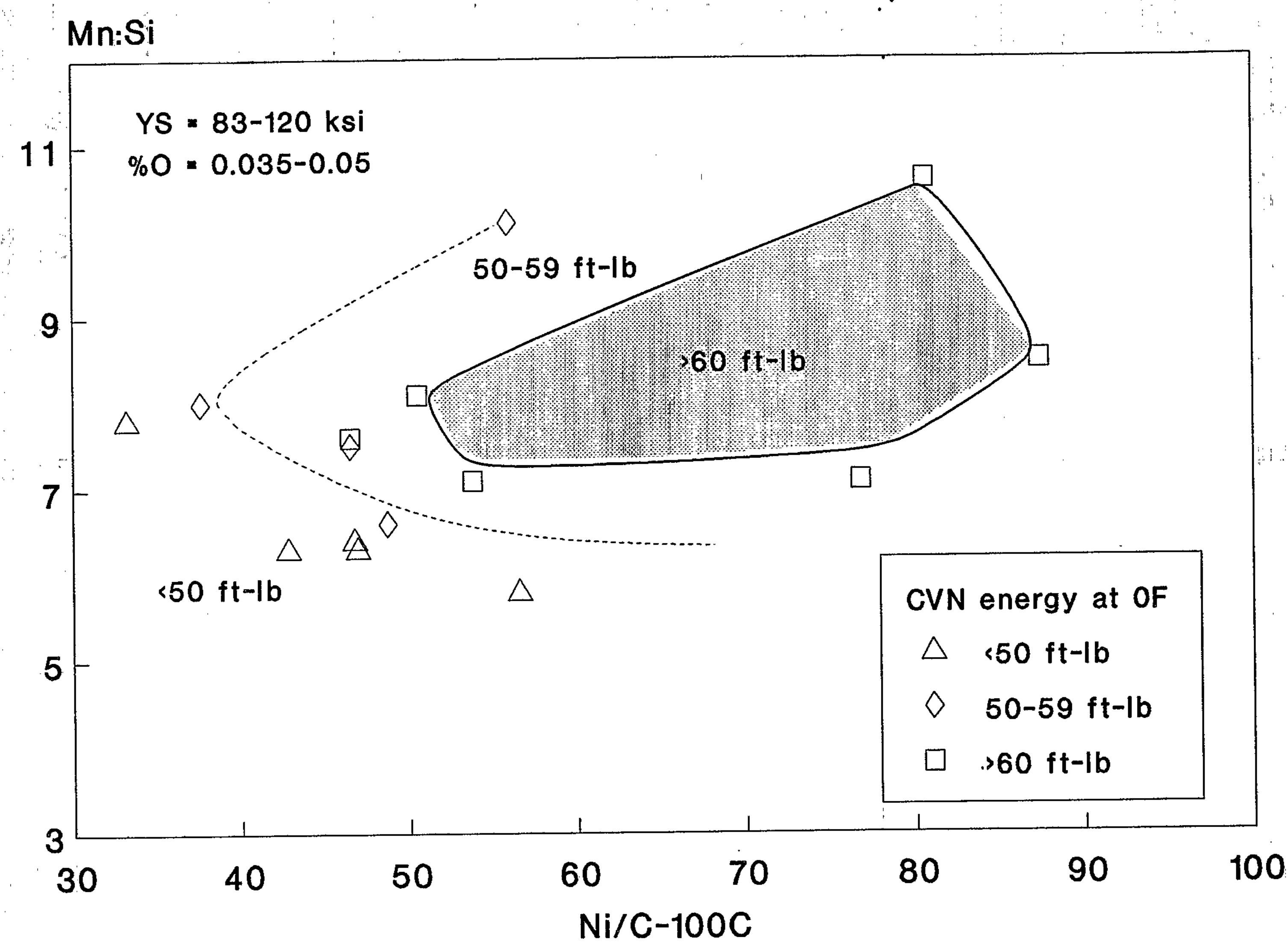
Formulation	C	Ni	Mo	Ti	Mn	Ti/N	Si	O	Yield Strength (ksi)	CVN at 0°F (ft-lb)	CVN at -60°F (ft-lb)
17	0.048	2.57	0.50	0.018	1.52	2.25	0.23	0.042	99	51	38
18	0.044	2.68	0.51	0.015	1.27	1.25	0.22	0.039	99	38	25
19	0.049	2.50	0.49	0.021	1.70	2.10	0.23	0.020	108	60	47
20	0.057	3.90	0.62	0.016	1.50	1.78	0.22	0.042	122	33	27
21	0.064	3.15	0.61	0.023	1.57	2.55	0.25	0.036	118	48	39
22	0.058	3.06	0.61	0.022	1.52	3.14	0.24	0.038	110	46	39
23	0.057	2.99	0.59	0.023	1.48	2.30	0.23	0.043	111	48	36
24	0.065	3.30	0.46	0.015	1.39	1.67	0.25	0.023	112	48	40
25	0.033	6.90	0.58	0.018	1.46	2.57	0.24	0.049	129	24	21
Target Properties									102-122	60 min	45 min



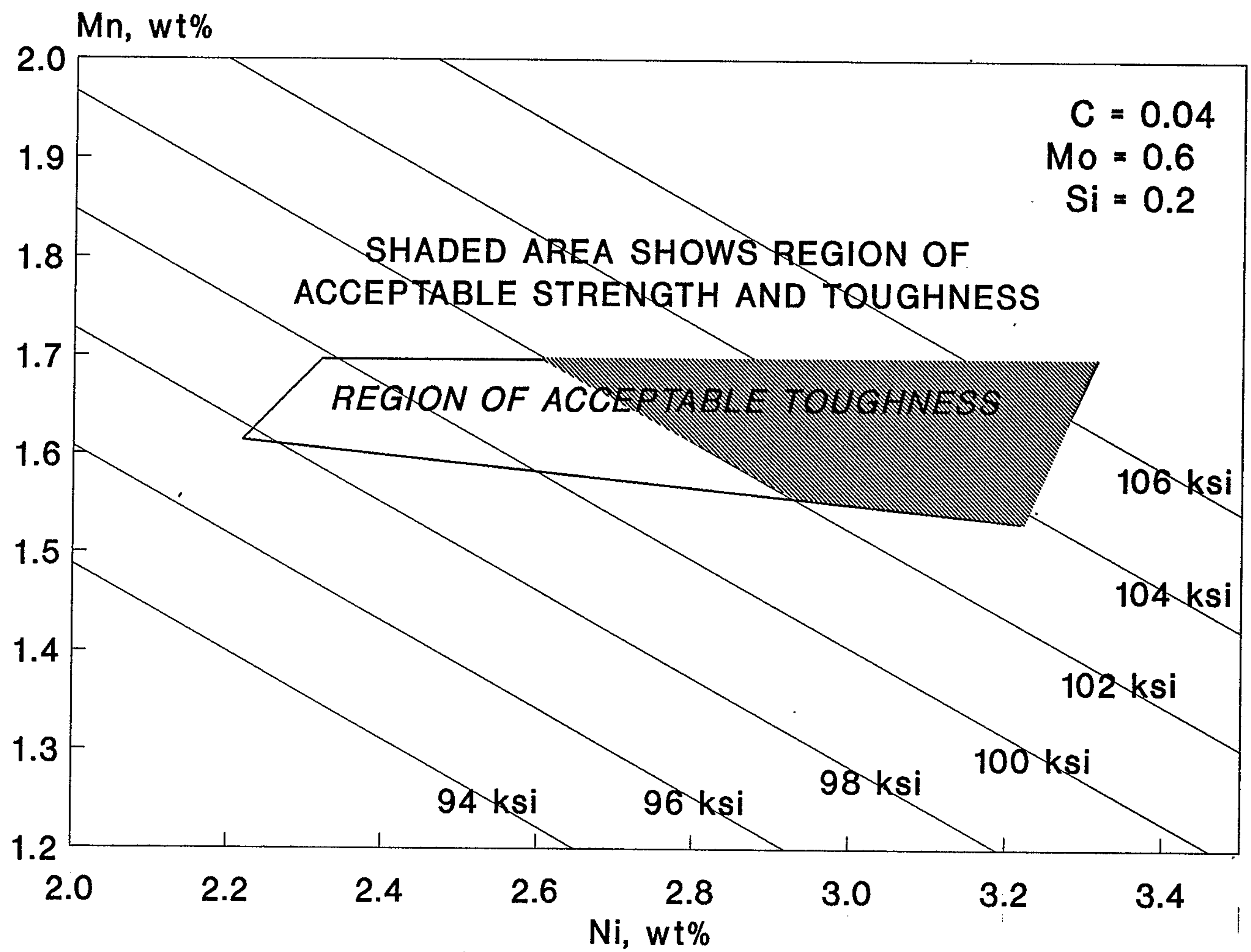
Effect of composition on yield strength.



Effect of composition on CVN energy at -60°F.



Effect of composition on CVN energy at 0°F.



Example of graphical method of identifying the compositional range that provides acceptable mechanical properties.

LOW CARBON BAINITIC WELD METAL

* Is high strength (>100ksi) low carbon (<0.02C) weld metal possible?

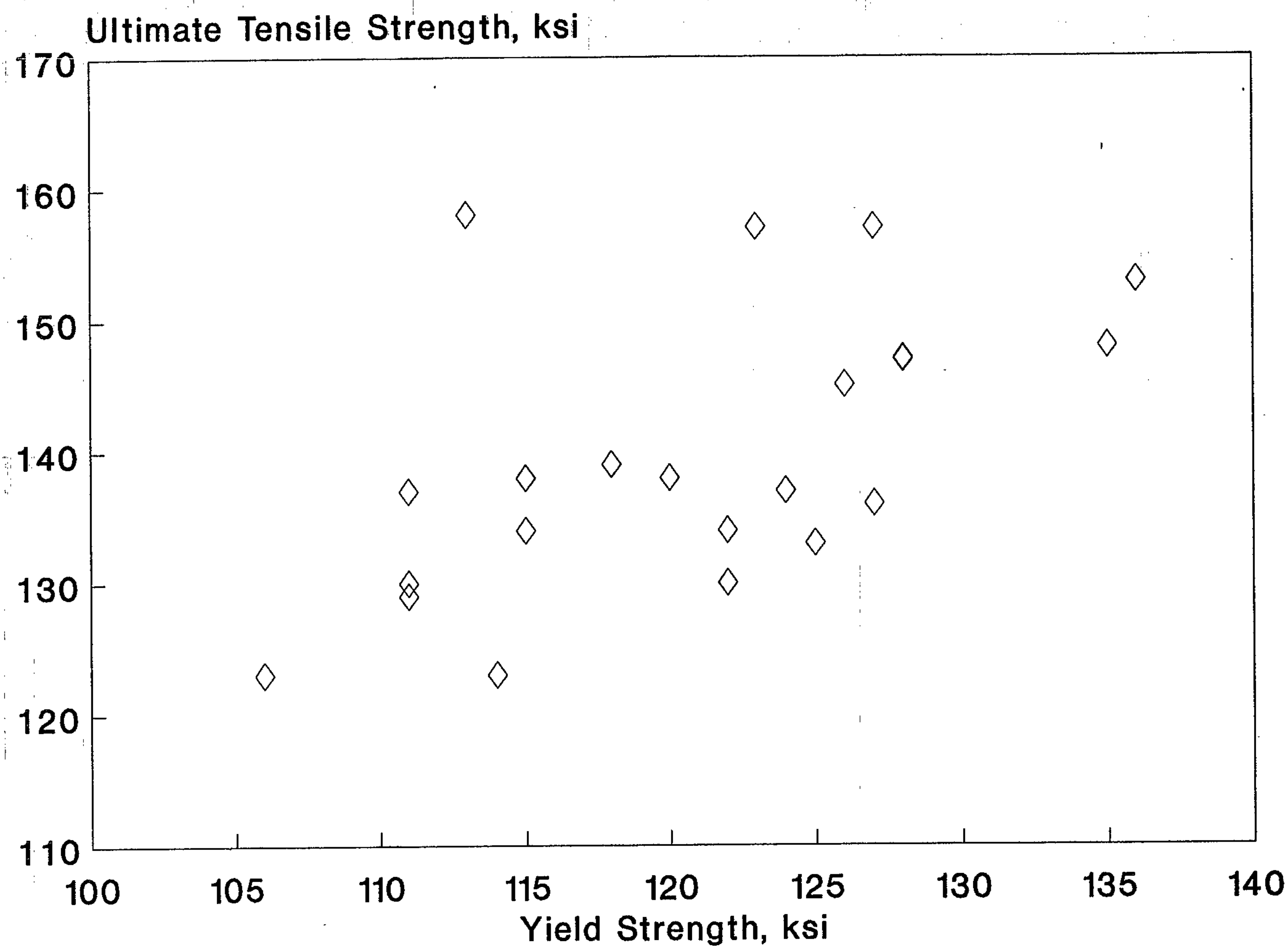
* Is the strength of such a weld metal less cooling rate sensitive than conventional (martensitic) types?

* Can necessary toughness be developed?

LOW CARBON BAINITIC WELD METAL

COMPOSITION RANGES

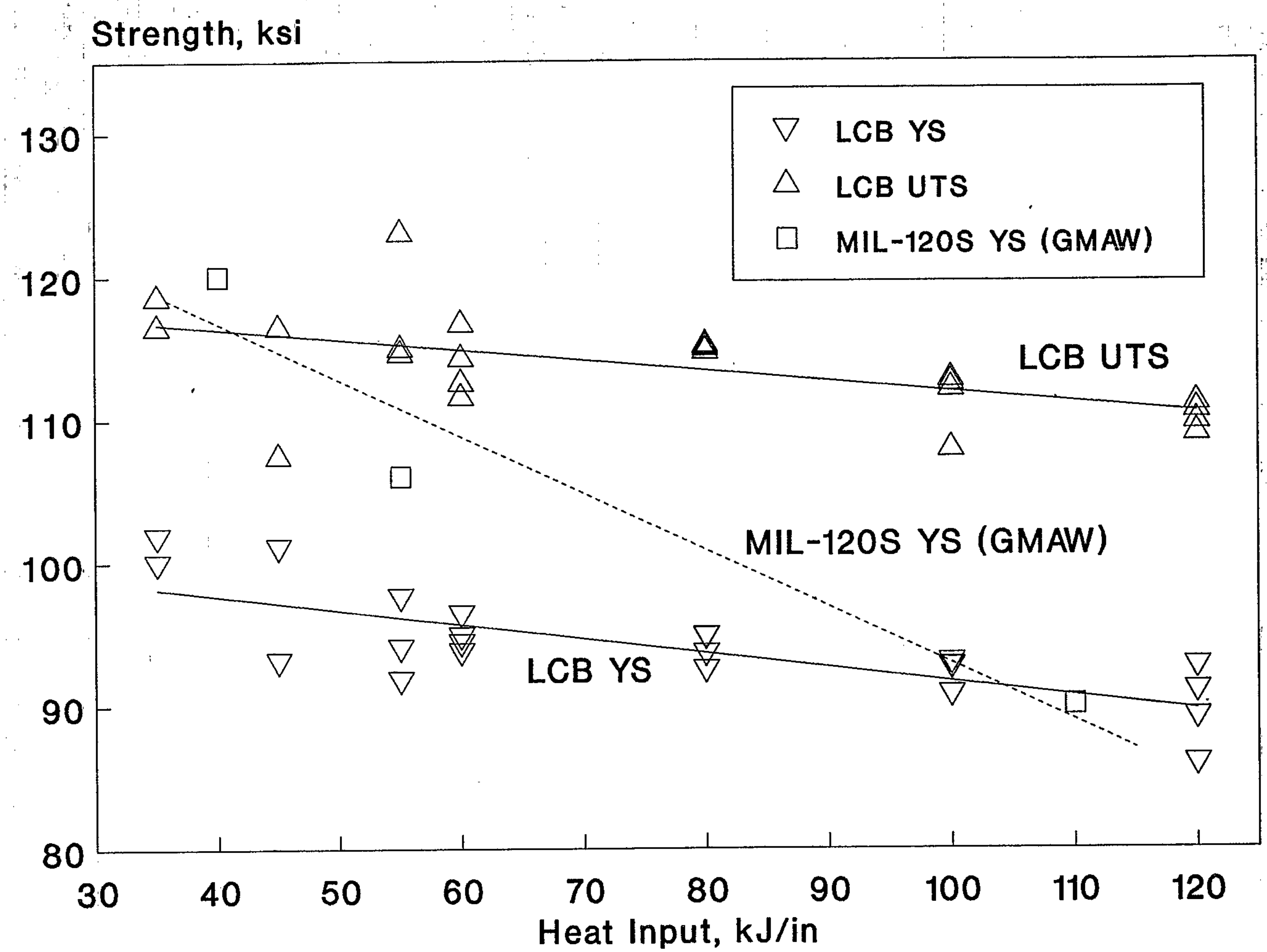
C	<0.02
Mn	1.0 - 2.0
Mo	1.5 - 5.0
Ni	2.5 - 5.0
Ti	0.10 - 0.25
Nb	<0.10



Tensile test results for LCB weld metals.

Change in weld metal yield strength (ksi) per % alloying

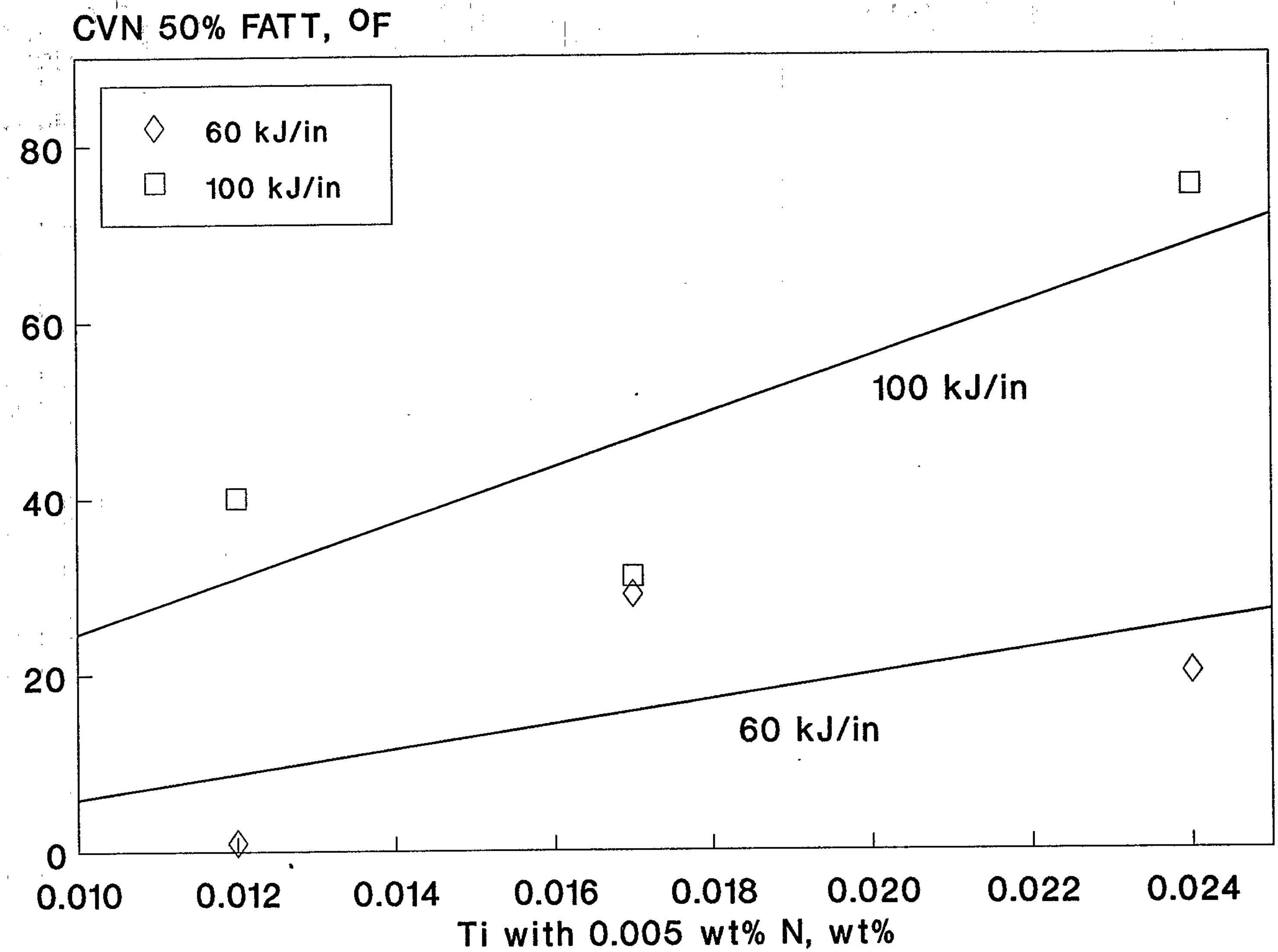
	Element Addition															
	<3.5% Ni		>3.5% Ni		Mo		C		<1.5% Mn		>1.5% Mn		<0.045% Nb		>0.045% Nb	
Heat Input (kJ/in)	60	120	60	120	60	120	60	120	60	120	60	120	60	120	60	120
at low Mo (2.5%)	6.25	4.17	-2.3	-1.1	---	---	76.9	230	22.5	18.4			261	130		
at high Mo (3.5%)	4.52	9.03	4.52	9.03	---	---	875	625	30.6	21.3	1.3	-1.3	267	133	467	333
at low Ni (2.5%)	---	---	---	---	4.72	4.72										
at high Ni (3.5%)	---	---	---	---	-1	2							140	70		
at high Mn (2.0%)					-3.1	-2.1			---	---	---	---				
Heuschkel [22]	3.9	3.9	3.9	3.9	17.6	17.6	115	115	15.3	15.3	15.3	15.3	---	---	---	---
Pickering [23]	1.1	1.1	1.1	1.1	17.4	17.4	247	247	12	12	12	12	168	168	168	168



Effect of welding heat input on LCB weld metal strength.

LOW CARBON BAINITIC WELD METAL
COOLING RATE SENSITIVITY

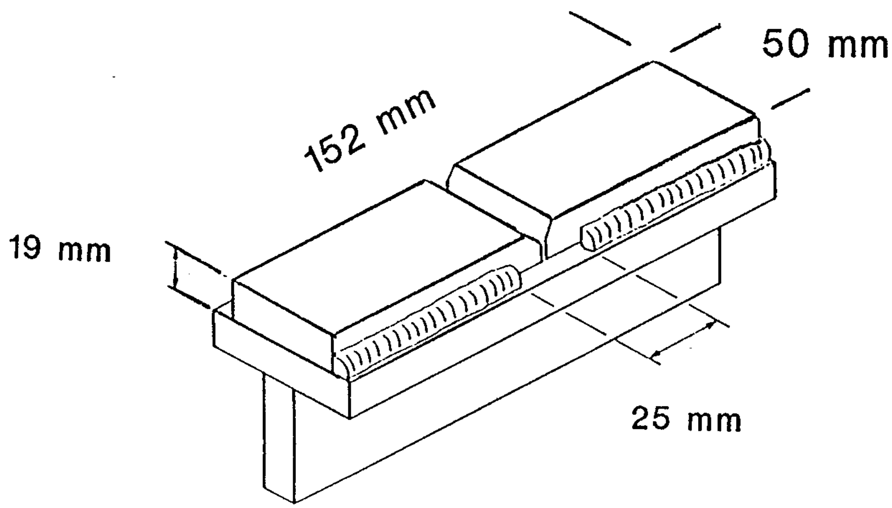
* Reduced with low carbon
* Ni & Mo produced best strength with least cooling rate sensitivity
* Mn, Nb & C increased strength but also cooling rate sensitivity



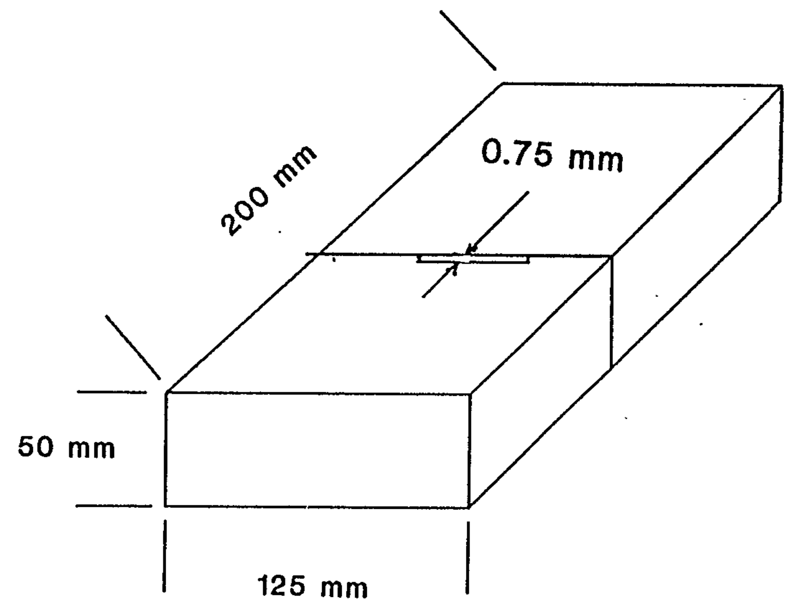
Effect of TiN on LCB weld metal impact performance.

WELD METAL CRACKING TESTS

WELDING INSTITUTE OF CANADA HIGH RESTRAINT CRACKING TEST (WIC)



GAPPED BEAD ON PLATE TEST (GBoP)



WELDABILITY METHODOLOGY
COOLING TIME PARAMETER (SUZUKI)

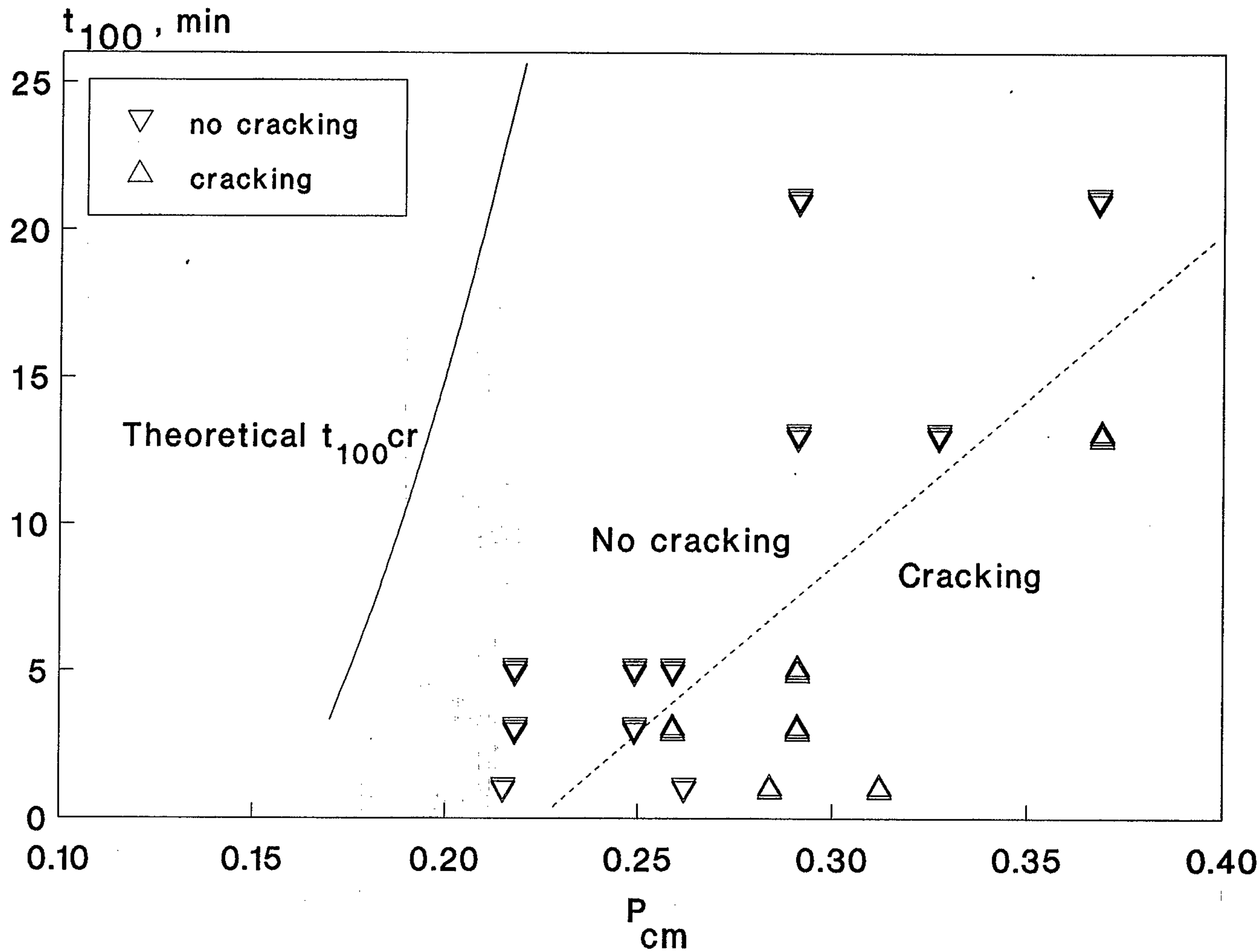
$$t_{100}cr = (1.145)*(P_{HA}^2) + (864)*(P_{HA}) - 171$$

where: $P_{HA} = \log(\lambda * H_D) + (11.9)*(P_{CM}) + (0.000089)*(R_{FY}) - 2.55$

λ = 0.6 for low hydrogen electrodes

H_D = weld metal diffusible hydrogen

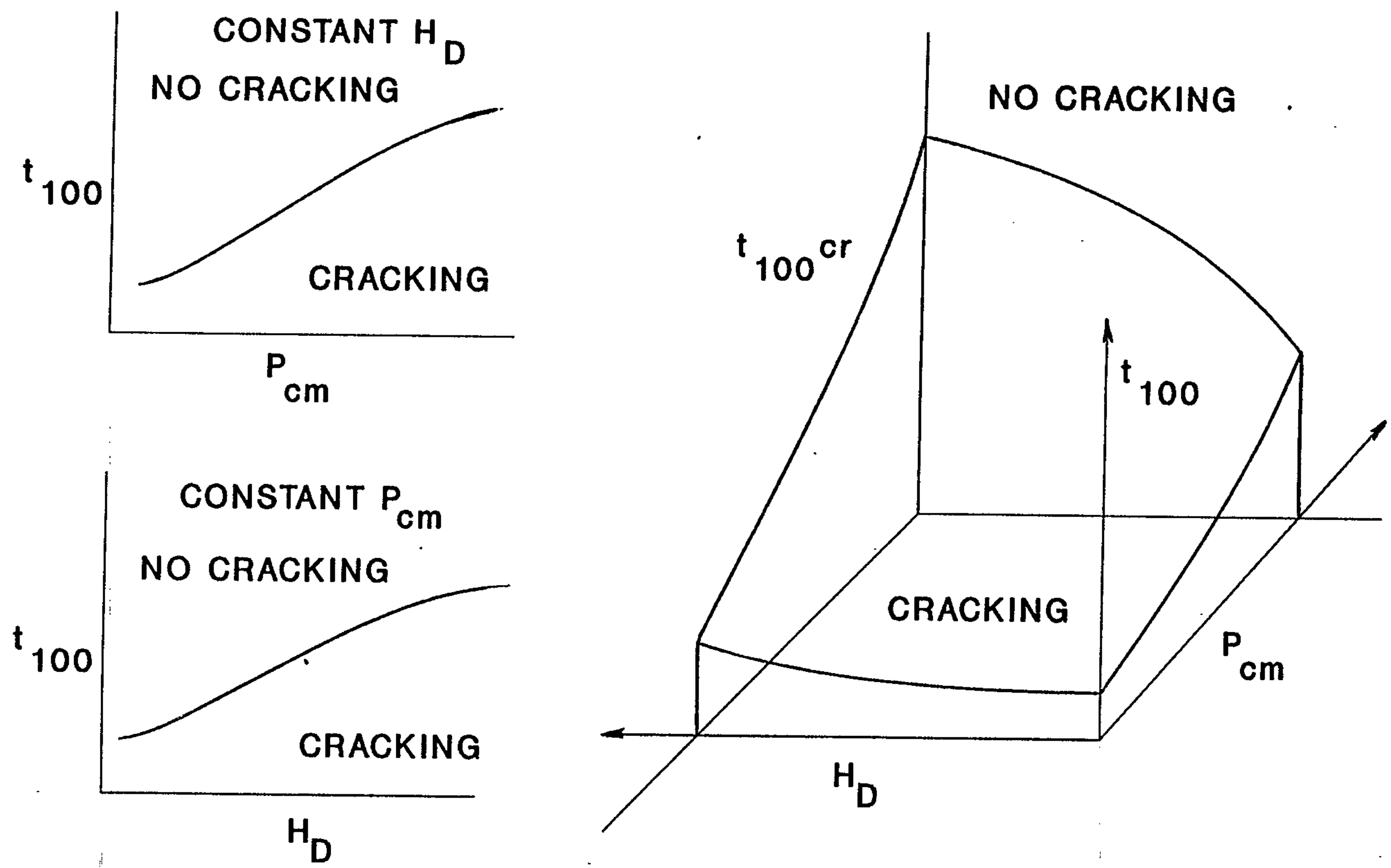
R_{FY} = intensity of restraint.



Results of WIC and GBoP weldability tests using SMAW consumables

Results of WIC weldability tests performed at ambient temperature for HSLA-100 steel and a MIL-100S welding consumable.

Hydrogen in Shielding Gas, %	H_D ml/100g	P_{CM}	Extent of Cracking, %
0	4.7	0.23	0
0.3	7.5	0.22	0
0.6	10.0	0.25	96
0.9	14.7	0.25	100



Schematic response surface for hydrogen cracking resistance.

WELDING FLUXES
COMPOSITION DETERMINATION

Optical Emission Spectroscopy (OES) - 35 elements

X-Ray Fluorescence (XRF) - 10 elements

Inductively Coupled Plasma - 44 elements

Selective Ion Electrode Technique - Fluorine

Submerged arc welding flux composition.

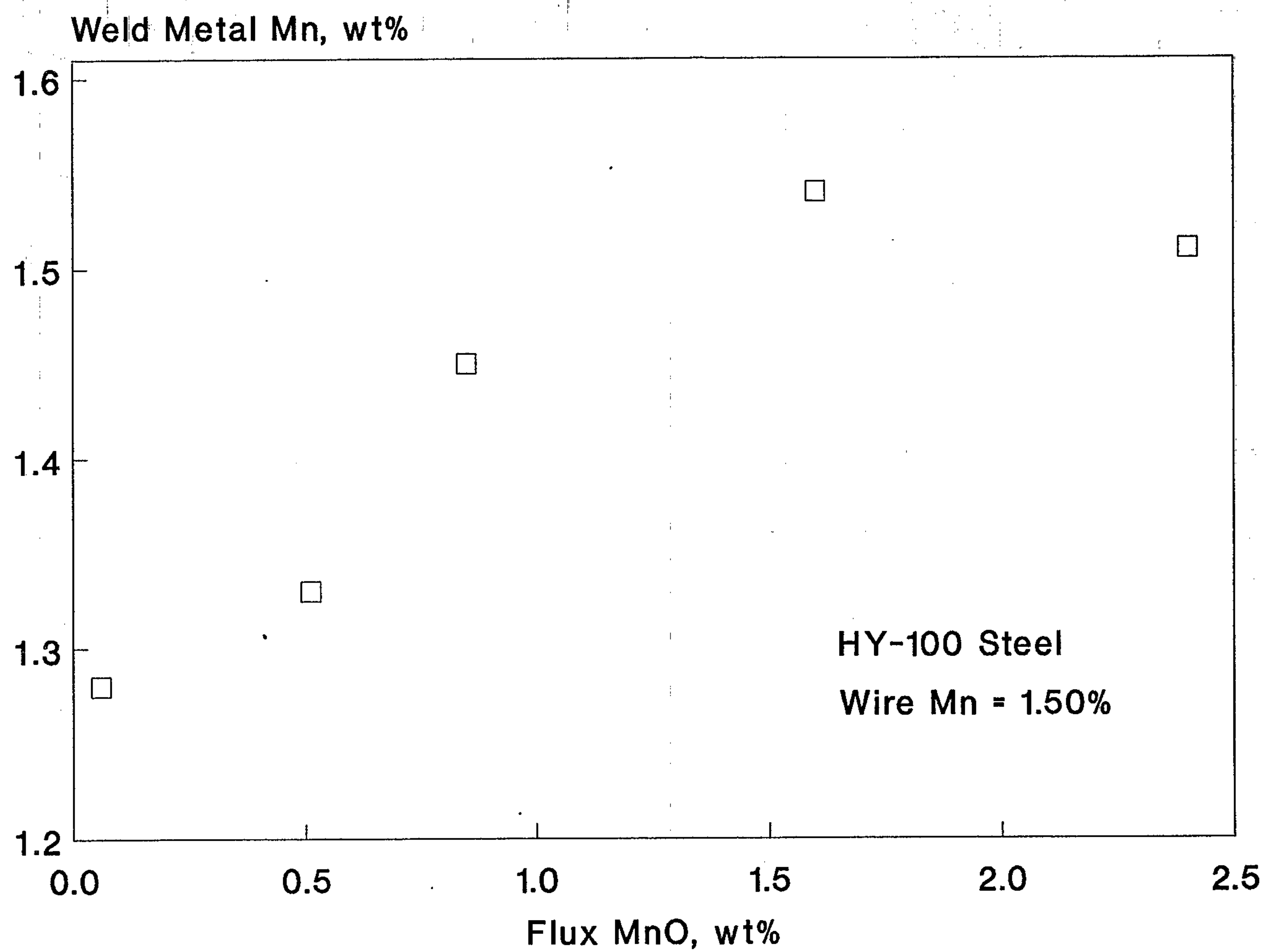
Compound	FLUX AA7	FLUX EC2	FLUX CB2	Flux FC2	Flux HD2
SiO_2	14.7	13.3	16.5	14.5	15.6
MgO	28.9	32.5	28.3	32.1	35.0
CaO	10.2	11.6	17.3	9.9	8.1
CaF_2	22.2	22.2	14.0	20.9	17.2
Al_2O_3	18.2	14.1	13.1	15.4	16.9
Fe_2O_3	1.09	1.09	1.19	1.05	2.00
TiO_2	0.72	-	-	0.52	0.68
MnO	0.89	0.45	0.05	1.60	2.52
K_2O	0.99	1.08	1.24	1.34	0.39
Na_2O	0.94	1.01	1.99	1.20	1.23
BaO	0.050	0.017	0.027	0.009	0.035
SrO	0.009	0.013	0.014	0.006	0.025
CeO_2	0.004	-	0.326	0.006	0.014
La_2O_3	0.006	0.002	0.269	0.007	0.009
Nd_2O_3	-	-	0.093	-	0.007
ZrO_2	0.04	0.03	-	0.08	0.04
B.I. [40]	2.66	3.40	2.75	2.97	2.63

Chemistry of welding consumable and submerged arc weld metal.

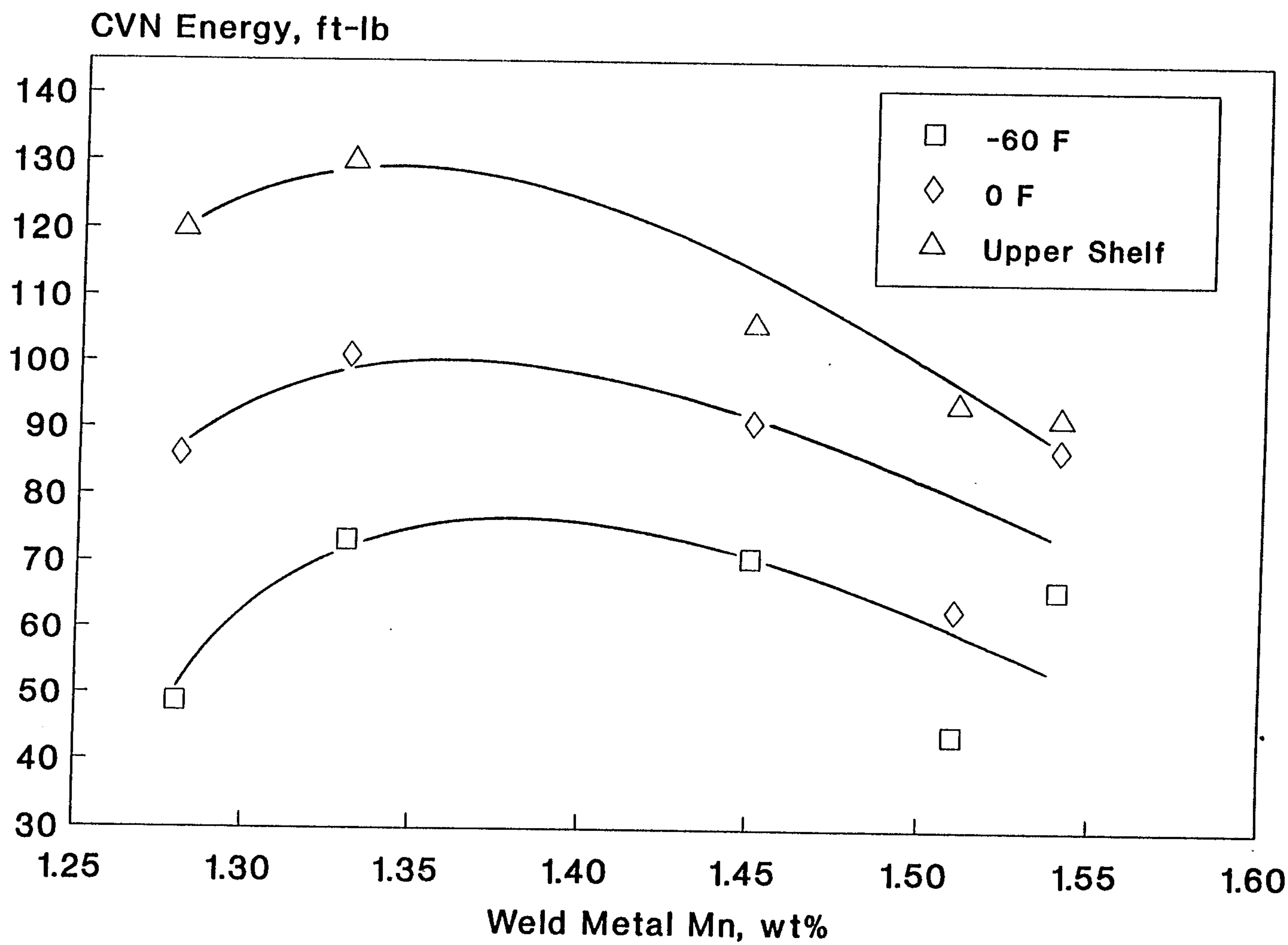
Element	Wire	FLUX AA7	FLUX EC2	FLUX CB2	Flux FC2	Flux HD2
C	0.081	0.062	0.063	0.056	0.064	0.064
Mn	1.50	1.45	1.33	1.28	1.54	1.51
Si	0.40	0.38	0.28	0.42	0.34	0.28
Ni	2.25	2.33	2.33	2.51	2.34	2.34
Mo	0.42	0.46	0.45	0.47	0.49	0.47
Cr	0.28	0.25	0.41	0.40	0.50	0.47
Ti	0.014	0.006	0.004	0.004	0.006	0.005
Cu	0.011	0.020	0.020	0.017	0.026	0.021
Al	0.012	0.013	0.012	0.011	0.014	0.011
V	0.001	0.003	0.002	0.002	0.003	0.004
B	0.004	0.004	0.004	0.004	0.001	0.004
O	0.003	0.030	0.032	0.034	0.032	0.035
P_{CM}	0.269	0.250	0.249	0.248	0.256	0.264

Properties for submerged arc weld metals.

Property	FLUX AA7	FLUX EC2	FLUX CB2	Flux FC2	Flux HD2
YS (ksi)	101	100	100	120	102
CVN (avg, ft-lb)					
@ -60°F	71	73	49	66	44
@ 0°F	91	101	86	87	63
Upper Shelf	106	130	120	92	94
50% FATT (°F)	-65	-75	-49	-99	-52



Effect of flux MnO content on weld metal manganese content.



Effect of weld metal manganese content on CVN performance.