SAE The Engineering Society For Advancing Mobility Land Sea Air and Space® INTERNATIONAL
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SURFACE VEHICLE INFORMATION REPORT

An American National Standard

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Superseding J775 JAN88

ENGINE POPPET VALVE INFORMATION REPORT

Foreword—This Document has not changed other than to put it into the new SAE Technical Standards Board Format.

Poppet valves control combustion chamber induction and exhaust gas flow in reciprocating combustion engines. Poppet valves are manufactured from iron, nickel, titanium, and cobalt-base metallic alloys which are often welded together in various combinations.

Martensitic and austenitic steels are used for intake valves. Specially designed high temperature martensitic alloys, austenitic alloys, and superalloys are used for exhaust valves. Titanium alloys have been used for both intake and exhaust valves in some limited production, high performance applications. Special iron, nickel, and cobalt-base alloys are welded to many of the valve head alloys to improve seat face wear and corrosion resistance.

1. Scope—This specification supplies engineers and designers with:

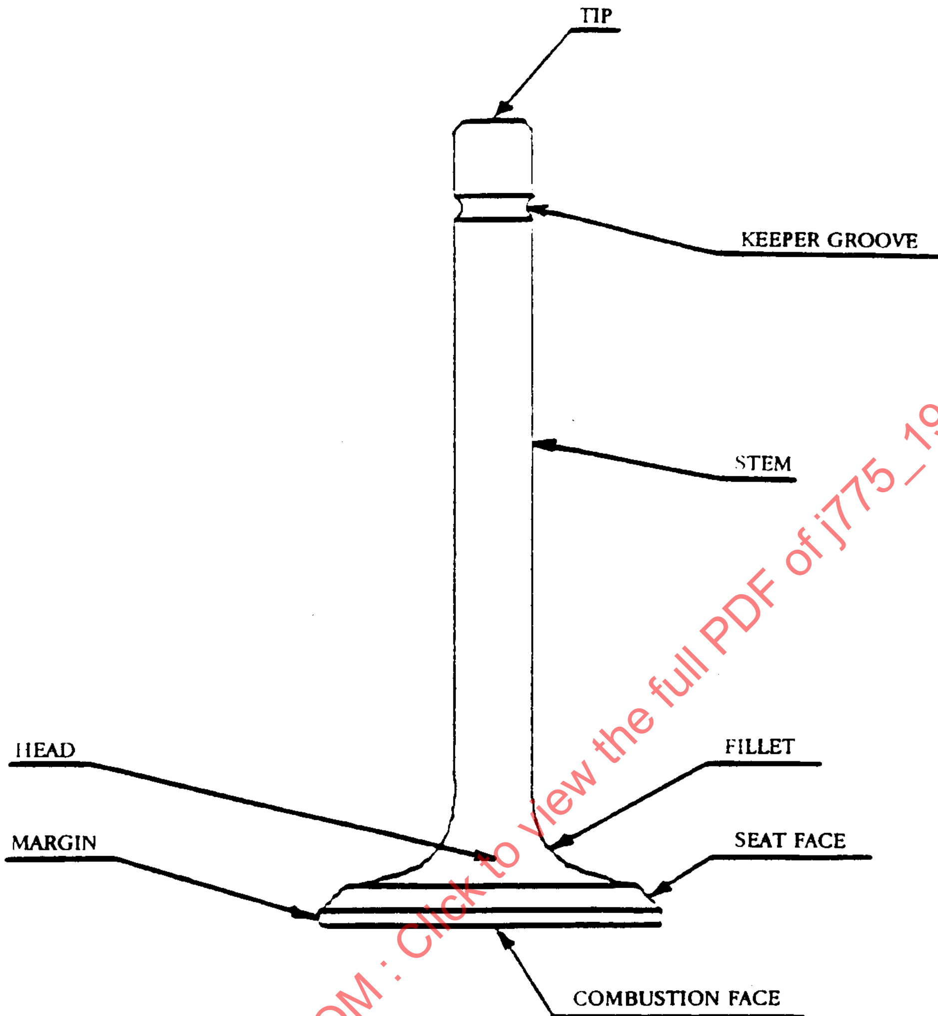
a. Poppet valve nomenclature
b. Poppet valve alloy designations
c. Chemical compositions of poppet valve alloys
d. A guide to valve alloy metallurgy and heat treatments
e. General information on properties of valve alloys
f. A guide to the application of valve alloys
g. A description of valve design and construction, and their relation to valve alloy selection
h. Valve gear design considerations that affect valves

2. References—There are no referenced publications specified herein.

3. Valve Nomenclature—Valve nomenclature and constructions are illustrated in Figures 1 to 5.

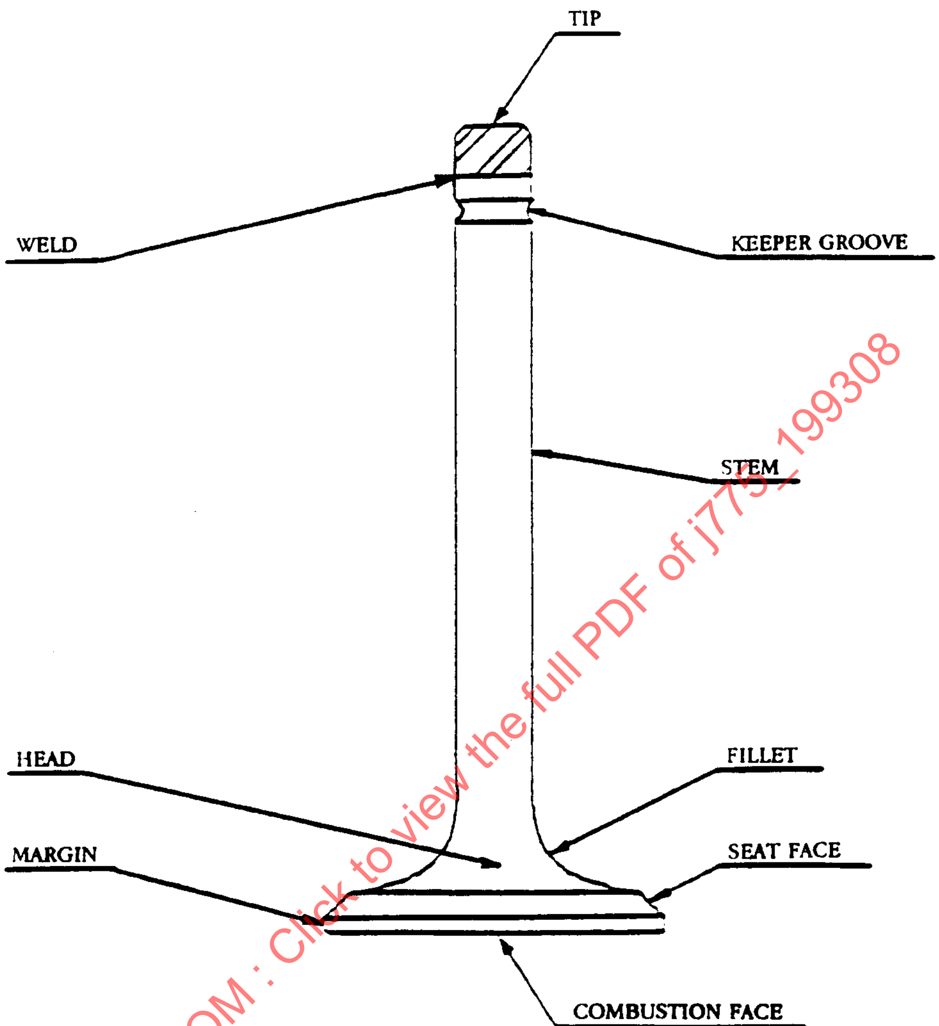
4. Valve Alloy Designation

4.1 UNS Designations—SAE, in conjunction with American Society for Testing and Materials (ASTM), has adopted the Unified Numbering System (UNS) for the identification of all metallic alloys. Tables 1A to 1E use the UNS identification codes for valve alloys. These UNS numbers supersede the previous SAE functional numbering system, which is still included for reference purposes.



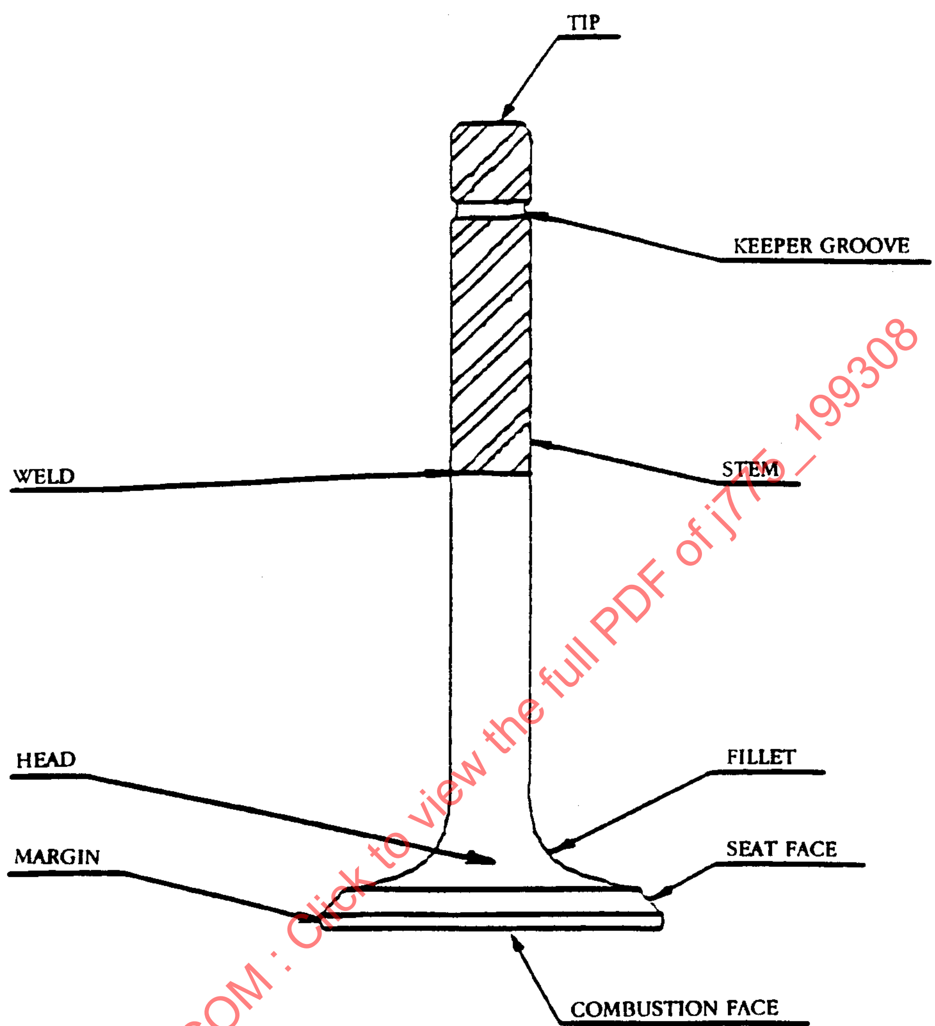
The majority of intake valves for all applications are one-piece construction which also has significant usage in spark ignition engine exhaust valves.

FIGURE 1—ONE-PIECE CONSTRUCTION



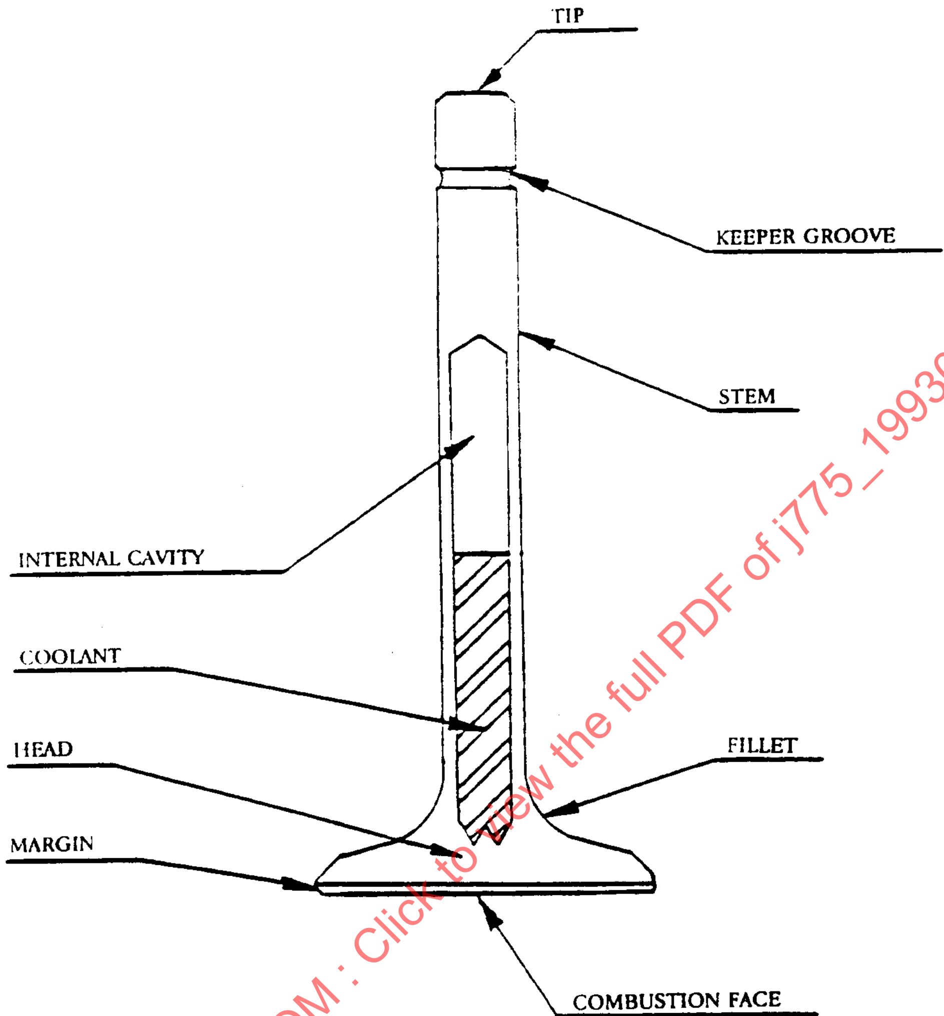
Welded tip construction has significant usage in spark and compression ignition engine exhaust valves.

FIGURE 2—WELDED TIP CONSTRUCTION



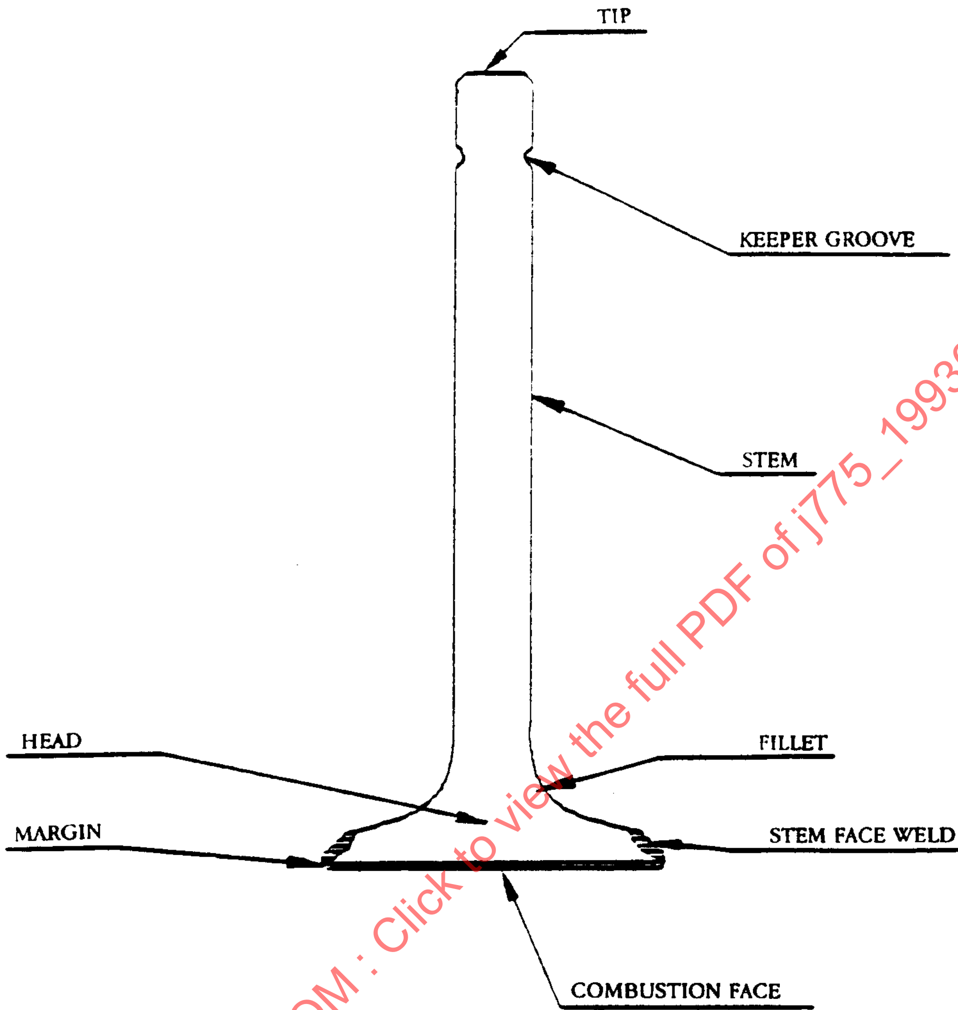
Two-piece construction has significant usage in spark and compression ignition engine exhaust valves.

FIGURE 3—TWO-PIECE CONSTRUCTION



Internally-cooled construction is used in extreme duty truck, high performance, and aircraft spark ignition engine exhaust valves.

FIGURE 4—INTERNALLY-COOLED CONSTRUCTION



Welded seat face construction predominates in compression ignition engine exhaust valves and has some usage in other valves. It supplements other types of valve construction.

FIGURE 5—WELDED SEAT FACE CONSTRUCTION

TABLE 1A—CURRENT NORTH AMERICAN VALVE ALLOYS (MARTENSITIC STEELS)

UNS NR/ ISO 683/15	COMMERCIAL	FORMER SAE GRADE	C	Mn	P (max)	S (max)	Si	Cr	Ni	W	Mo	Fe	Other
H15410	1541H	NV1	0.35/0.45	1.25/1.75	0.040	0.050	0.15/0.35	-	-	-	-	Base	
G15470	1547	NV 2	0.43/0.51	1.35/1.65	0.040	0.050	-	-	-	-	-	Base	
G31400	3140	NV 4	0.38/0.43	0.70/0.90	0.040	0.040	0.15/0.35	0.55/0.75	1.10/1.40	-	-	Base	
G86450	8645	NV 5	0.43/0.48	0.75/1.00	0.035	0.040	0.15/0.35	0.40/0.60	0.40/0.70	-	0.15/0.25	Base	
H51500	5150H	NV 6	0.47/0.54	0.60/1.00	0.035	0.040	0.15/0.35	0.60/1.00	-	-	-	Base	
H41400	4140H	NV 7	0.37/0.44	0.65/1.10	0.035	0.040	0.15/0.35	0.75/1.20	-	-	0.15/0.25	Base	
K14072	B16		0.36/0.44	0.45/0.70	0.040	0.040	0.15/0.35	0.80/1.15	-	-	0.50/0.65	Base	V 0.25/0.35
	GM-8440	NV 8	0.35/0.45	0.20/0.40	0.030	0.040	3.60/4.20	1.85/2.50	0.25 max	-	0.10 max	Base	Cu 0.25 max
S65007/X 45 CrSi 9 3	Sil 1	HNV 3	0.40/0.50	0.80 max	0.040	0.030	2.70/3.30	8.00/10.00	0.60 max	-	-	Base	
S65006	Sil XB	HNV 6	0.75/0.90	0.80 max	0.040	0.040	1.75/2.60	19.00/ 21.00	1.00/1.70	-	-	Base	
S42200	422 SS	HNV 8	0.20/0.25	1.00 max	0.040	0.030	0.75 max	11.00/ 12.50	0.50/1.00	0.75/ 1.25	0.75/1.25	Base	V 0.15/0.30 Cu 0.50 max
S64004	SUH 11M		0.47/0.55	0.60 max	0.030	0.030	1.00/2.00	7.50/9.50	0.60 max	-	-	Base	

All chemical contents are expressed in weight percent.

TABLE 1B—CURRENT NORTH AMERICAN VALVE ALLOYS (AUSTENITIC STEELS)

UNS NR/ISO 683/15	COMMERCIAL	FORMER SAE GRADE	C	Mn	P (max)	S (max)	Si	Cr	Ni	N	Fe	Other
S63017	21-12N	EV 4	0.15/0.25	1.00/1.50	0.045	0.030	0.70/1.25	20.00/22.00	10.50/ 12.50	0.15/0.25	Base	
S63008/ X 53 CrMnNiN21 9	21-4N	EV 8	0.48/0.58	8.00/10.00	0.050	0.030	0.25 max	20.00/22.00	3.25/4.50	0.35/0.50	Base	
S63012	21-2N	EV 12	0.50/0.60	7.00/10.00	0.050	0.030	0.25 max	19.25/21.50	1.50/2.75	0.20/0.40	Base	
S63013	Gaman H	EV 13	0.47/0.57	11.00/13.00	0.030	0.050	2.00/3.00	20.00/22.00	-	0.40/0.50	Base	
S63018/ X 33 CrNiMnN 23 8	23-8N	EV 16	0.28/0.38	1.50/3.50	0.050	0.030	0.50/1.00	22.00/24.00	7.00/9.00	0.25/0.35	Base	Mo 0.50 max W 0.50 max
S30430	302 HQ	EV 17	0.10 max	2.00 max	0.045	0.030	1.00 max	17.00/19.00	8.00/10.00	-	Base	Cu 3.00/4.00
S63019/ X 50 CrMnNiNbN 21 9	21-4N + Nb + W	XEV-F	0.45/0.55	8.00/10.00	0.050	0.030	0.45 max	20.00/22.00	3.50/5.50	0.40/0.60	Base	W 0.80/1.50 Nb + Ta 1.80/2.50

All chemical contents are expressed in weight percent.

TABLE 1C—CURRENT VALVE ALLOYS (SUPERALLOYS)

UNS NR/ISO 683/15	COMMERCIAL	FORMER SAE GRADE	C	Mn (max)	P (max)	S (max)	Si (max)	Cr	Ni	Co	Mo	Fe	Other
N07751/ NiCr 15 Fe 7 TiAl	Inconel 751	HEV 3	0.03/0.10	0.50	0.015	0.015	0.50	14.00/17.00	Base	1.00 max	0.50 max	5.00/9.00	Ti 2.00/2.60 Al 1.10/1.35 Nb + Ta 0.70/1.20 Zr 0.04/0.10 B 0.0015/0.009 Cu 0.50 max
N07080/ NiCr 20 TiAl	Nimonic 80-A	HEV 5	0.04/0.10	1.00	0.020	0.015	1.00	18.00/21.00	Base	2.00 max	-	3.00 max	B 0.008 max Zr 0.04/0.10 Ti 1.80/2.70 Al 1.00/1.80 Cu 0.20 max
N07032	Pyromet 31V	HEV 8	0.03/0.06	0.20	0.015	0.015	0.20	22.30/22.90	55.00/58.00	1.00 max	1.70/ 2.30	Balance	Ti 2.10/2.40 Al 1.10/1.40 Nb 0.70/1.00 B 0.003/0.007 Cu 0.50 max
N07001	Waspaloy	XEV-H	0.03/0.10	1.00	0.030	0.030	0.75	18.00/21.00	Base	12.00/ 15.00	3.50/ 5.00	2.00 max	Ti 2.75/3.25 Al 1.20/1.60 Zr 0.02/0.12 B 0.003/0.010 Cu 0.50 max

All chemical contents are expressed in weight percent.

TABLE 1D—CURRENT VALVE ALLOYS (FACING ALLOYS)

UNS NR	COMMERCIAL	FORMER SAE GRADE	C	Mn (max)	P (max)	S (max)	Si	Cr	Ni	Co	W	Mo	Fe	Other
R30006	Stellite 6	VF 2	0.90/1.40	1.00	0.030	0.030	1.50 max	26.00/ 32.00	5.00 max	Base	3.50/5.50	1.50 max	6.00 max	
N06005	Eatonite	VF 3	2.00/2.75	0.50	0.030	0.030	0.50/1.00	27.00/ 31.00	Base	9.00/11.00	14.00/16.00	–	8.00 max	
N06782	X-782	VF 4	1.75/2.25	1.00	0.030	0.030	0.50 max	25.00/ 27.00	Base	0.50 max	8.00/9.50	–	4.00 max	
R30002	Stellite F	VF 5	1.50/2.00	1.00	0.030	0.030	0.80/1.50	23.00/ 27.00	20.50/ 23.50	Base	10.50/13.50	1.00 max	6.00 max	
R30001	Stellite 1	VF 6	2.00/3.00	1.00	0.030	0.030	0.40/2.00	26.00/ 33.00	3.00 max	Base	11.00/14.00	1.00 max	6.00 max	
R30012	Stellite 12	VF 7	1.10/1.70	1.00	0.030	0.030	0.40/2.00	26.00/ 33.00	3.00 max	Base	7.00/9.50	1.00 max	3.00 max	
R30400	Tribaloy T-400	VF 8	0.08 max	–	0.030	0.030	2.20/3.00	7.50/10.00	–	61.00/ 63.00	–	26.50/ 30.00	–	Fe + Ni 3.00 max
N06013	Eatonite 3	VF 9	1.80/2.20	1.00	0.030	0.030	0.80/1.20	28.00/ 30.00	Base	–	–	4.00/6.00	1.00/8.00	
N06015	Eatonite 5	VF 10	1.80/2.20	1.00	0.030	0.030	0.80/1.20	28.00/ 30.00	Base	–	–	7.00/9.00	1.00/8.00	
	VMS 585	VF 11	2.00/2.50	–	–	–	0.80/1.30	22.00/ 26.00	10.00/ 12.00	–	–	5.00/6.00	Base	
S68000														
	Eatonite 6		1.50/2.00	1.00	0.025	0.020	1.10/1.50	26.00/ 30.00	15.00/ 18.00	–	–	4.00/5.00	Base	
	Tribaloy T-800		0.08 max	–	0.030	0.030	3.00/3.80	16.50/ 18.50	1.50 max	Base	–	27.00/ 30.00	1.50 max	

All chemical contents are expressed in weight percent.

TABLE 1E—CURRENT VALVE ALLOYS (TITANIUM ALLOYS)

UNS NR	COMMERCIAL	FORMER SAE GRADE	C (max)	Al	V	Zr	Mo	Sn	O (max)	Fe (max)	H (max)	Y (max)	Ti	Other (max)
R56401	Ti 6-4	XEV-J	0.10	5.25/6.75	3.35/4.65	–	–	–	0.40	0.80	0.020	0.005	Base	N 0.10
R54620	Ti 6-2-4-2		0.05	5.50/6.50	–	3.60/4.40	1.80/2.20	1.80/2.20	0.20	0.25	0.015	0.005	Base	Si 0.20 N 0.07

All chemical contents are expressed in weight percent.

Each UNS designation is a five-digit identification number preceded by a type identification prefix letter. Valve alloys have six identification prefixes:

G - General purpose carbon and low alloy structural steels
H - Controlled hardenability carbon and low alloy steels
K - Special purpose iron-base alloys
N - Nickel-base alloys
R - Cobalt, titanium, and other refractory alloys
S - Stainless steels, heat-resistant steels, corrosion-resistant steels, and iron-base superalloys

The five-digit identification number often incorporates the most popular previous designation for the alloy. The UNS designations are controlled by individual SAE and ASTM committees which work in concert.

4.2 Obsolete SAE Functional Designations—The former SAE numbering system was based on the type of valve for which the material was commonly used. Numbers were assigned on the following bases:

a. Letter Prefix—Intake valves may be made of carbon, low alloy, or heat and corrosion resistant high-alloy steels. The prefix NV designated carbon and low alloy intake valve steels. HNV designated high alloy intake valve steels.
   Exhaust valves may be made of hardenable martensitic steels, austenitic steels, or superalloys. Alloys used for exhaust valves may be iron, nickel, or cobalt-base alloys. The prefix letters EV designated austenitic exhaust valve steels. The letters HEV were used for high strength exhaust valve alloys in severe spark and compression ignition engine service.
   The prefix VF designated high alloy valve seat facing overlays used at critical points of wear or corrosion.
   The prefix X designated experimental and limited usage alloys preceding a conventional prefix, such as XEV.

b. Number Suffix—A number was arbitrarily assigned, based on the order in which the alloy was codified.

4.3 Other Designations—Tables 2A to 2C list other important national and international valve alloys, together with their specific chemistries.

5. Valve Alloy Chemical Compositions

5.1 General—There are many overlapping and conflicting specifications for the chemical compositions of valve alloys. This specification adopts the ISO chemical compositions from their Regulation 683/15. Unfortunately, a number of alloys in common use are not listed in this regulation, so lowest common denominator compositions, conforming with most specifications in common usage, were developed.

5.2 UNS (SAE) Compositions—The UNS (SAE) standard compositions for valve alloys are listed in Tables 1A to 1E.

5.3 Other Compositions—The compositions of other international valve alloys are listed in Tables 2A to 2C.

TABLE 2A—ISO VALVE ALLOYS

UNS NR	ISO 683/15	C	Mn	P (max)	S (max)	Si	Cr	Ni	N	W	Mo	Fe	Other
S65007	x 45 CrSi 9 3	0.40/0.50	0.80 max	0.040	0.030	2.7/3.3	8.0/10.0	0.60 max	–	–	–	Base	
	X 50 CrSi 8 2	0.45/0.55	0.60 max	0.030	0.030	1.0/2.0	7.5/9.5	0.60 max	–	–	–	Base	
	X 85 CrMoV 18 2	0.80/0.90	1.5 max	0.040	0.030	1.0 max	16.5/18.5	–	–	–	2.0/2.5	Base	V 0.30/0.60
S63008	X 53 CrMnNiN 21 9	0.48/0.58	8.0/10.0	0.050	0.030	0.25 max	20.0/22.0	3.25/4.5	0.35/0.50	–	–	Base	
	X 55 CrMnNiN 20 8	0.50/0.60	7.0/10.0	0.050	0.030	0.25 max	19.5/21.5	1.5/2.75	0.20/0.40	–	–	Base	
S63018	X 33 CrNiMnN 23 8	0.28/0.38	1.5/3.5	0.050	0.030	0.50/1.00	22.0/24.0	7.0/9.0	0.25/0.35	0.50 max	0.50 max	Base	
S63019	X 50 CrMnNiNbN 21 9	0.45/0.55	8.0/10.0	0.050	0.030	0.45 max	20.0/22.0	3.5/5.5	0.40/0.60	0.80/1.50	–	Base	Nb + Ta 1.80/2.50
	X 53 CrMnNiNbN 21 9	0.48/0.58	8.0/10.0	0.050	0.030	0.45 max	20.0/22.0	3.25/4.5	0.38/0.50	–	–	Base	C + N ρ 0.90 Nb + Ta 2.00/3.00
N07080	NiCr 20 TiAl	0.04/0.10	1.0 max	0.020	0.015	1.0 max	18.0/21.0	Base	–	–	–	3.0 max	Al 1.0/1.8 Ti 1.8/2.7 Co 2.0 max Cu 0.2 max B 0.008 max
N07751	NiCr 15 Fe 7 TiAl	0.03/0.10	0.50 max	0.015	0.015	0.50 max	14.0/17.0	Base	–	–	0.50 max	5.0/9.0	Al 1.10/1.35 Nb + Ta 0.70/1.20 Ti 2.0/2.6
	NiFe 25 Cr 20 NbTi	0.10 max	1.0 max	0.030	0.015	1.0 max	18.0/21.0	Base	–	–	–	23.0/28.0	Al 0.30/1.00 Nb + Ta 1.0/2.0 B 0.008 max

All chemical contents are expressed in weight percent.

TABLE 2B—JIS HEAT RESISTING STEELS (VALVE ALLOYS)

UNS NR	JASO GRADE	C	Mn	P (max)	S (max)	Si	Cr	Ni	Co	W	Mo	Fe	Other
R30001	Co Cr 1	2.00/3.00	1.00 max	-	-	0.40/2.00	26.0/33.0	3.00 max	Base	11.00/14.00	1.00 max	3.00 max	0.50 max
R30006	Co Cr 6	0.90/1.40	1.00 max	-	-	0.40/2.00	26.0/32.0	3.00 max	Base	3.00/6.00	1.00 max	3.00 max	0.50 max
R30012	Co Cr 12	1.20/1.70	1.00 max	-	-	0.40/2.00	26.0/33.0	3.00 max	Base	7.00/9.50	1.00 max	3.00 max	0.50 max

All chemical contents are expressed in weight percent.

UNS NR	JIS G 4106 GRADE	C	Mn	P (max)	S (max)	Si	Cr	Ni	Co	W	Mo	Fe	Other
G15470	SMnC443	0.40/0.46	1.35/1.65	0.030	0.030	0.15/0.35	0.35/0.70	-	-	-	-	-	

All chemical contents are expressed in weight percent.

UNS NR	JIS G 4103 GRADE	C	Mn	P (max)	S (max)	Si	Cr	Ni	Co	W	Mo	Fe	Other
G86450	SNCM 240	0.38/0.43	0.70/1.00	0.030	0.030	0.15/0.35	0.40/0.65	0.40/0.70	-	-	0.15/0.30	-	

All chemical contents are expressed in weight percent.

UNS NR	JIS G 4311 GRADE	C	Mn	P (max)	S (max)	Si	Cr	Ni	Co	W	Mo	Fe	Other
S65007	SUH 1	0.40/0.50	0.60 max	0.030	0.030	3.00/3.50	7.50/9.50	0.60 max	-	-	-	-	
S65006	SUH 4	0.75/0.85	0.20/0.60	0.030	0.030	1.75/2.25	19.00/20.50	1.15/1.65	-	-	-	-	
S63008	SUH 35	0.48/0.58	8.00/10.00	0.040	0.030	0.35 max	20.00/22.00	3.25/4.50	-	-	-	-	N 0.35/0.50
S63017	SUH 37	0.15/0.25	1.00/1.60	0.040	0.030	1.00 max	20.50/22.50	10.00/12.00	-	-	-	-	N 0.15/0.30
S42200	SUH 616	0.20/0.25	0.50/1.00	0.040	0.030	0.50 max	11.00/13.00	0.50/1.00	-	0.75/1.25	0.75/1.25	-	V 0.20/0.30

All chemical contents are expressed in weight percent.

TABLE 2C—JIS HEAT RESISTING STEELS (VALVE ALLOYS)

UNS NR	JIS G 4902 GRADE	C	Mn (max)	P (max)	S (max)	Si (max)	Cr	Ni	Fe	Other
N07080	NCF 80A	0.04/0.10	1.00	0.030	0.015	1.00	18.00/21.00	Base	1.50 max	Ti 1.80/2.70 Al 1.00/1.80 Cu 0.20 max
	NCF 751	0.10 max	1.00	0.030	0.015	0.50	14.00/17.00	70.00 min	5.00/9.00	Ti 2.00/2.60 Al 0.90/1.50 Nb + Ta 0.70/1.20 Cu 0.50 max

All chemical contents are expressed in weight percent.

6. Valve Alloy Metallurgy and Heat Treatment

6.1 General—The performance characteristics of a valve alloy are a cross product of composition and heat treatment. Alloy selection depends upon stresses, corrosive agents, and temperatures encountered in service, as well as the economic and durability objectives. Heat treatments used to improve the mechani cal properties of valves depend upon the specific alloy, economics, and the level of properties desired. They can be general or selective, and it is not uncommon for a single valve to be subjected to two or more heat treatments in different locations.

6.2 Martensitic Alloys—Plain carbon, low alloy, and high alloy martensitic steels are primarily used for intake valves. Extreme duty martensitic steels generally have the highest carbon and alloy content to resist wear, to resist seat face indention by deposits, and to provide increased strength. Elements such as chromium and silicon are added when increased oxidation or corrosion resistance is needed. Manganese and nickel are added as strengthening agents. Occasionally, refractory elements, such as molybdenum, tungsten, and vanadium are used to enhance certain elevated temperature properties.

Martensitic valves are most often quench hardened and tempered to hardness readings in the 25 to 45 Rockwell "C" scale range. This is a compromise among good strength, adequate ductility, impact performance, and wear resistance along the stem. In some less demanding applications, martensitic valves can be used in the annealed condition.

Tips and seats are often selectively hardened to create high hardness and wear resistant surfaces. These surfaces are selectively hardened, generally to the greatest hardness practical for the alloy. Tip hardening may extend beyond the keeper groove to improve the fatigue strength and the wear resistance of this region.

6.3 Austenitic Alloys—Austenitic alloys have a face-centered cubic crystal structure which is termed austenite. The elements that stabilize the austenitic structure are carbon, manganese, nickel, copper, and nitrogen. Chromium, silicon, and sometimes, aluminum are added for oxidation or corrosion resistance. Refractory elements such as molybdenum, niobium, tantalum, tungsten, and vanadium may be added for high temperature strength. These alloys are termed steels when the base element is iron. The cobalt and nickel-base austenitic materials are termed superalloys. Iron-base austenitic steels are hardened by carbonitride precipitation. Nickel-base superalloys are hardened by precipitation of aluminum, nickel, niobium, tantalum, and titanium in the form of intermetallic compounds. They may be used in either wrought or cast form, although cast valves are diminishing in commercial importance.

Austenitic valve alloys may be as simple in composition as 18-8 stainless steels, or as complicated as gas turbine alloys. The selection is strongly influenced by economic considerations, as well as the mechanical, physical, and chemical attributes required to satisfy specific engine requirements.

Mechanical properties are improved in austenitic valve alloys by precipitation hardening or strain hardening, rather than the martensitic transformation hardening of low alloy steels. The most common austenitic alloy hardening processes are:

a. High temperature forging followed by aging heat treatment(s)
b. High temperature forging followed by a solution treatment and then aging heat treatment(s)
c. Cold forming

In lower temperature applications, austenitic engine valves are frequently used in the forged and aged condition. More severe and higher temperature service generally requires solution treatment followed by one or more aging treatments. These operations produce hardness readings in the 20 to 40 Rockwell "C" scale range. The hardness developed depends upon the capability of the individual alloy. These alloys develop fatigue, creep, wear, and seat face indentation resistance from the heat treatments.

The cold formed austentic alloys (302HQ) are often used in small light-duty engines.

6.4 Titanium Alloys—Titanium alloys can be divided into three categories: alpha, alpha-beta, and beta alloys. Alpha alloys have a close-packed hexagonal structure, beta alloys have a body-centered cubic structure, and alpha-beta alloys have mixtures of the two different structures. The alloying elements that stabilize the alpha structure include oxygen, nitrogen, aluminum, and carbon. Alloying elements that stabilize the beta structure include vanadium and molybdenum. Zirconium and tin have minor effects upon phase stability, but are widely used as solid-solution strengtheners in both alpha and beta alloys.

Most titanium intake valves are made from alpha-beta alloys which have superior low temperature strength. Exhaust valves are generally manufactured from alpha or near alpha alloys because they have better high temperature creep properties. Beta alloys have not been used in any engine valve applications of consequence.

Titanium alloy heat treatments for engine valve applications are less established than the heat treatments for high volume production alloys. Most titanium alloys used in engine valves are precipitation hardenable and receive some type of solution treatment and aging after forming.

It is important to note that the development of titanium alloy engine valves has been primarily for high performance applications where extended durability is not a primary concern. Heat treatment procedures and precision are believed to be critical parameters in long-term titanium valve durability.

Titanium aluminides are being investigated on an experimental basis for passenger car exhaust valve applications.

6.5 Ceramic Materials—Although not yet used in any commercial applications, ceramic materials are being investigated for high temperature valve service. The primary material being investigated for this application is Si_3N_4. Much experimentation has been done to develop plasma sprayed cermets, but these are being used only on a limited basis.

6.6 Seat Facing Alloys—Seat facing alloys are composed of hard precipitates in cobalt, nickel, or iron-base austenitic matrices. The hard precipitates are generally chromium, molybdenum, tungsten, or vanadium carbides. Some compositions use intermetallic compounds, such as Laves phase, as the hard precipitates. Chromium is added to the matrix to increase corrosion resistance. Silicon additions provide the fluidity necessary for welding the facing to the valve seat and can improve wear resistance.

Seat facing alloys derive their wear resistance from the volume fraction of precipitates which possess great hot hardness and compressive strength. A significant portion of the adhesive wear resistance in these seat facing alloys, as well as other high chromium alloys, is derived from the tenacious chromium oxide layer formed on the wear surface by oxidation during service. When extremely severe conditions of corrosion are encountered, such as those which occur when sulfur-containing fuels are used, cobalt or iron-base hard-facing alloys may be required to assure valve seat durability.

Selection of a particular seat facing alloy usually depends upon temperatures, stresses, and corrodents encountered in service. Manufacturing considerations may preclude some seat facing alloy/valve head alloy combinations.

7. *Valve Alloy Physical and Mechanical Properties*

7.1 General—No single property can define the varying conditions encountered in different internal combustion engines. Spark and compression ignition engines place different demands on engine valves, so the properties of interest vary.

Common causes of valve failures include:

a. Adhesive or Abrasive Wear

1. Of the stem surface
2. Of the seat surface
3. Of the tip surface

b. General or Localized Corrosion

1. Primarily at elevated temperatures
2. Often combined with fatigue

c. Fatigue

1. Head radial cracking by thermal fatigue
2. Head chordal cracking by mechanical fatigue
3. Fillet transverse cracking by mechanical fatigue
4. Keeper groove transverse cracking by mechanical fatigue
5. Often assisted by corrosion

7.2 Wear Properties—The wear resistance of valve materials cannot be adequately assessed by a single type of wear or mechanical property test because of the different modes of wear encountered at different locations on the valve. Often a secondary mode of wear can be initiated by the wear particles generated by the primary wear mode. Valve wear service must be considered individually at each of these locations: valve tip, stem, and seat.

a. Valve Tip—Against rocker arm type valve gear, valve tips are subjected to combined sliding and rolling contact with the rocker arm surface, potentially causing adhesive wear.
b. Valve Stem—Valve stems are subjected to a normal amount of sliding wear, which is not severe unless aggravated by inadequate lubrication or applied transverse loads. Excessive transverse loads are often due to improper rocker arm geometry or thermal distortion of the cylinder seat.
c. Valve Seat—The valve seat/cylinder head seat contact is characterized by high normal stresses and severe sliding conditions, generally at high temperatures and in a corrosive environment. The high combustion pressures in heavy-duty compression-ignition engines impose high shear stresses across the contact interface which damage the seat face surfaces by sliding. Valve seat wear is often accelerated because of dimensional misalignment as a result of manufacturing variability or thermal distortion.

Valve wear performance is most often determined by evaluating valves that are run in durability test engines, but some laboratory tests are also used to rate the relative performance of alloys. These laboratory tests include:

a. Pin on disc tests
b. Crossed cylinder wear tests
c. Thrust washer tests
d. Cylinder - vee block tests
e. Functional tests of components in fixtures or actual engines

At the present time, there is little experience to suggest that the data generated by these tests can be used to design an engine valve from the first principles, but test data are invaluable in improving the wear performance of existing valve designs.

7.3 Corrosion Properties—Because of the variety of corrosive environments, there is no industry standard laboratory corrosion test. Some of the tests used to rate the corrosion resistance of valve alloys are:

a. Crucible immersion tests with various corrodents
b. Engine tests with a hole drilled through the head of the valve
c. Air oxidation tests run at high temperatures for a given time
d. Sulfidation tests using gas atmospheres

The corrosion of valves is accelerated by their temperature and environment. Corrosion occurs through four mechanisms:

a. Oxidation
b. Attack by various liquid metal oxides and salts
c. Attack by combustion products
d. Attack by fuel and lubricant additives or contaminants

Valve manufacturers and valve steel suppliers can generally supply representative corrosion resistance data.

7.4 Fatigue Properties—Fatigue data and corrosion-accelerated fatigue data are limited because of the lengthy testing programs required to generate meaningful data. The situation is improving, and more data are being gathered by valve and steel manufacturers. In lieu of these data, estimates of fatigue resistance are usually established on the basis of elevated temperature tensile, creep, and stress rupture performances.

The tensile properties of finished valves are dependent upon processing and heat treatment during manufacture. Typical tensile data for individual alloys are provided in Table 3. This table contains data of unknown origin, therefore, its accuracy cannot be presumed. The data should be used only as a guideline. Valve manufacturers can generally supply expected mechanical properties in different regions of a valve, once a design envelope is established.

7.5 Physical Properties—The physical properties of various valve steels and alloys are listed in Table 4. These data are of unknown origin and their accuracy cannot be presumed. The data should be used only as a guideline.

8. Valve Alloy Application

8.1 General—Alloys are selected for the body of the valve after considering the required mechanical and physical properties. Final selection and validation are usually decided, based on the outcome of engine tests. It is well worth noting that there are many thermodynamic adjustments that can be made to an engine system which dramatically change the operating environment of the valves. The cost penalties of the more sophisticated valve alloys which may be required must be considered when analyzing the benefits of thermodynamic cycle improvements.

The severity of valve duty is determined by the operating environment in which the valve functions. The preeminent environmental factors are temperature, imposed stress, and chemical activity. Poppet valve operating temperature is generally a function of combustion process efficiency and engine cooling system effectiveness. Peak engine firing pressures and the valve seating velocities determine the stresses of most concern in a valve. The combustion gases which flow past the exhaust valve can be quite active chemically and generally dictate the use of corrosion resistant alloys.

TABLE 3—TYPICAL MECHANICAL PROPERTIES OF VALVE ALLOYS(1)(2)

UNS NR	ISO 683/15	SAE GRADE	Temperature °C	Temperature (°F)	Tensile Properties Tensile Strength MPa	Tensile Properties Tensile Strength (ksi)	Tensile Properties Yield Strength MPa	Tensile Properties Yield Strength (ksi)	Tensile Properties Elongation %	Tensile Properties Reduction of Area %	Brinell Mutual Indentation BHN	Hot Hardness Cold Ball BHN 760 °C (1400 °F)
H15410		1541H	Room	Room	970	(141)	910	(132)	-	63	-	-
			540	(1000)	420	(61)	330	(48)	-	75	-	-
G15470		1547	Room	Room	1240	(180)	1140	(165)	-	40	-	-
G31400		3140	Room	Room	790	(114)	520	(76)	-	-	-	-
			540	(1000)	140	(21)	110	(16.1)	-	-	-	-
			650	(1200)	86	(12.5)	57	(8.3)	-	-	-	-
G86450		8645	Room	Room	1240	(180)	1140	(165)	-	40	-	-
H51500		5150H	Room	Room	990	(143)	910	(132)	-	57	-	-
H41400		4140H	Room	Room	900	(131)	800	(116)	-	-	-	-
			540	(1000)	500	(72)	390	(56)	-	-	-	-
		NV 8	Room	Room	920	(134)	690	(100)	-	53	-	-
			540	(1000)	270	(39)	220	(32)	-	44	-	-
			650	(1200)	130	(18.2)	110	(16.1)	-	97	-	-
S65007	X 45 CrSi 9 3	HNV 3	Room	Room	920	(133)	690	(100)	22	50	-	-
			650	(1200)	210	(31)	150	(22)	-	89	63	-
			760	(1400)	69	(10)	62	(9)	-	99	31	-
S65006		HNV 6	Room	Room	940	(136)	840	(122)	15.5	10	-	-
			650	(1200)	200	(29)	160	(23)	-	62	85	-
			760	(1400)	100	(14.5)	75	(10.9	72	80	40	70
S42200		HNV 8	Room	Room	1030	(149)	860	(125)	-	52	-	-
			650	(1200)	360	(52)	310	(45)	-	83	-	-
S63017		EV 4	Room	Room	820	(119)	430	(63)	26.2	20	-	-
			650	(1200)	420	(61)	230	(34)	-	18	100	-
			760	(1400)	300	(43)	220	(31)	13.3	18	80	115
S63008	X 53 CrMnNiN 21 9	EV 8	Room	Room	1140	(166)	740	(107)	-	9	-	-
			650	(1200)	590	(86)	330	(48)	-	18	185	-
			760	(1400)	430	(62)	260	(37)	18	25	100	193