Sept. 2, 1958 J. D. NISBET 2,850,385

MOLYBDENUM-BASE ALLOY

Filed Aug. 29, 1955 3 Sheets-Sheet 1

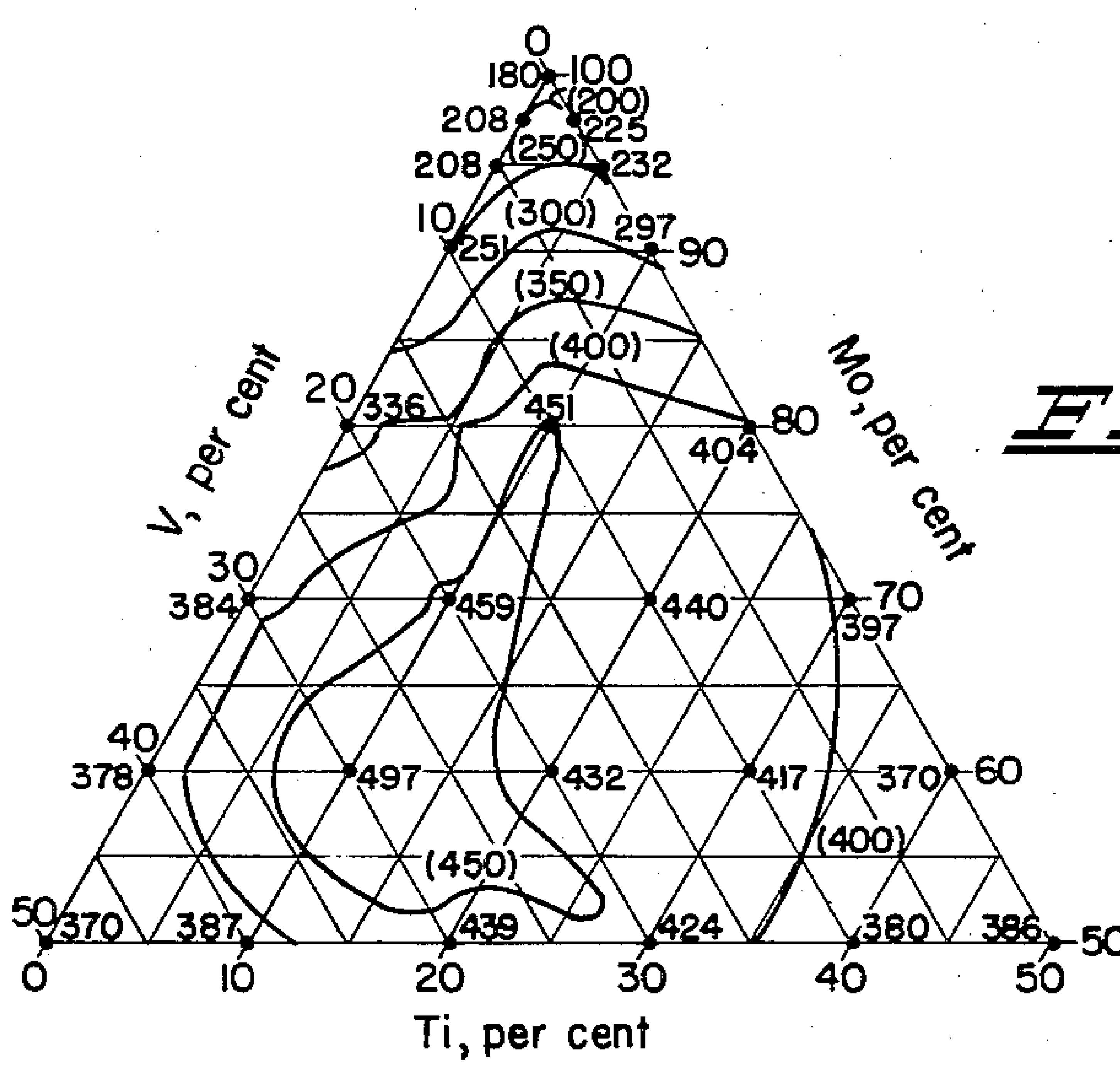
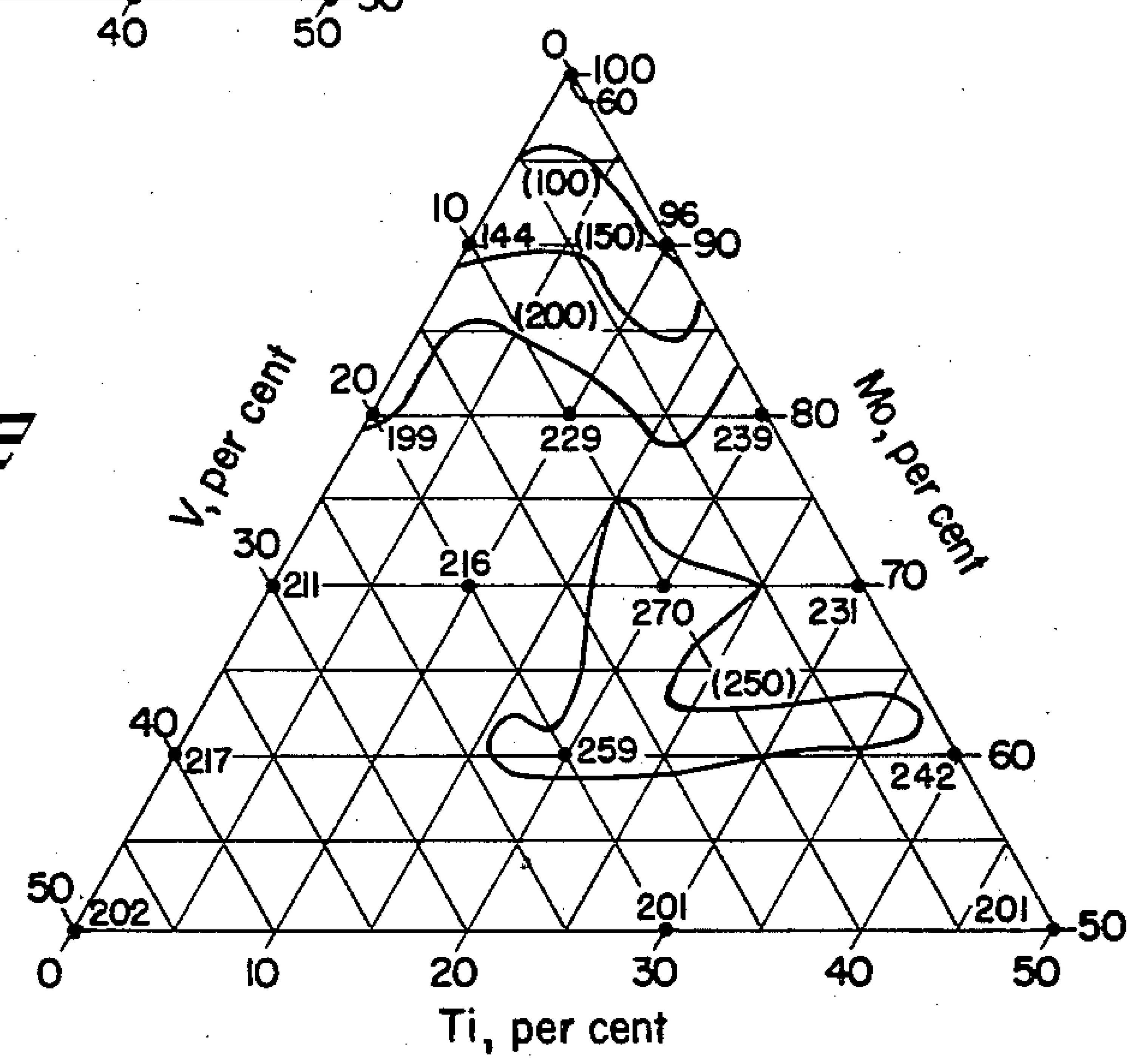


Fig-1

Fig-2



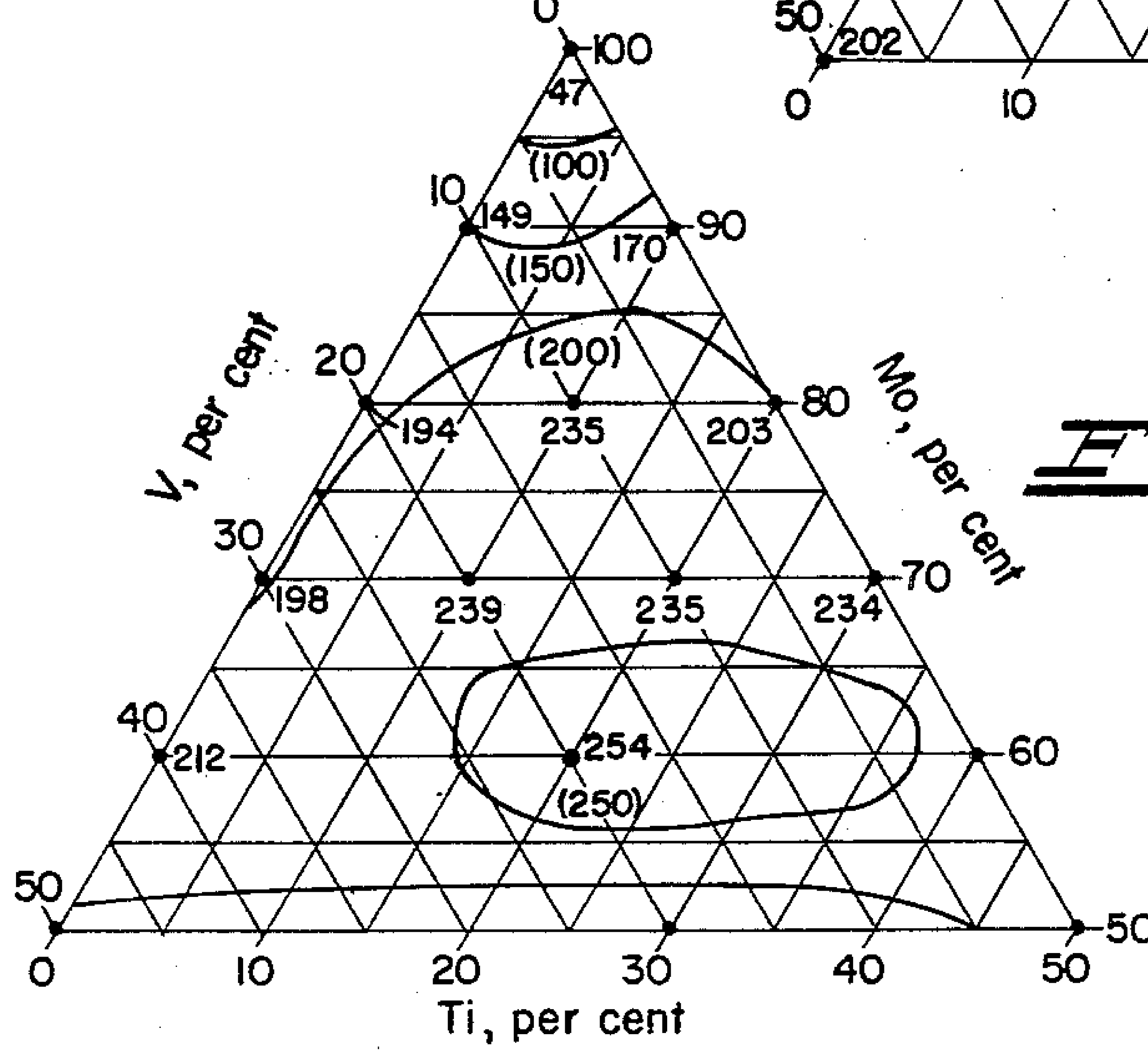


Fig-3

INVENTOR.
James D. Nisbet

BY Gray, Mase & Dunson
ATTORNEYS.

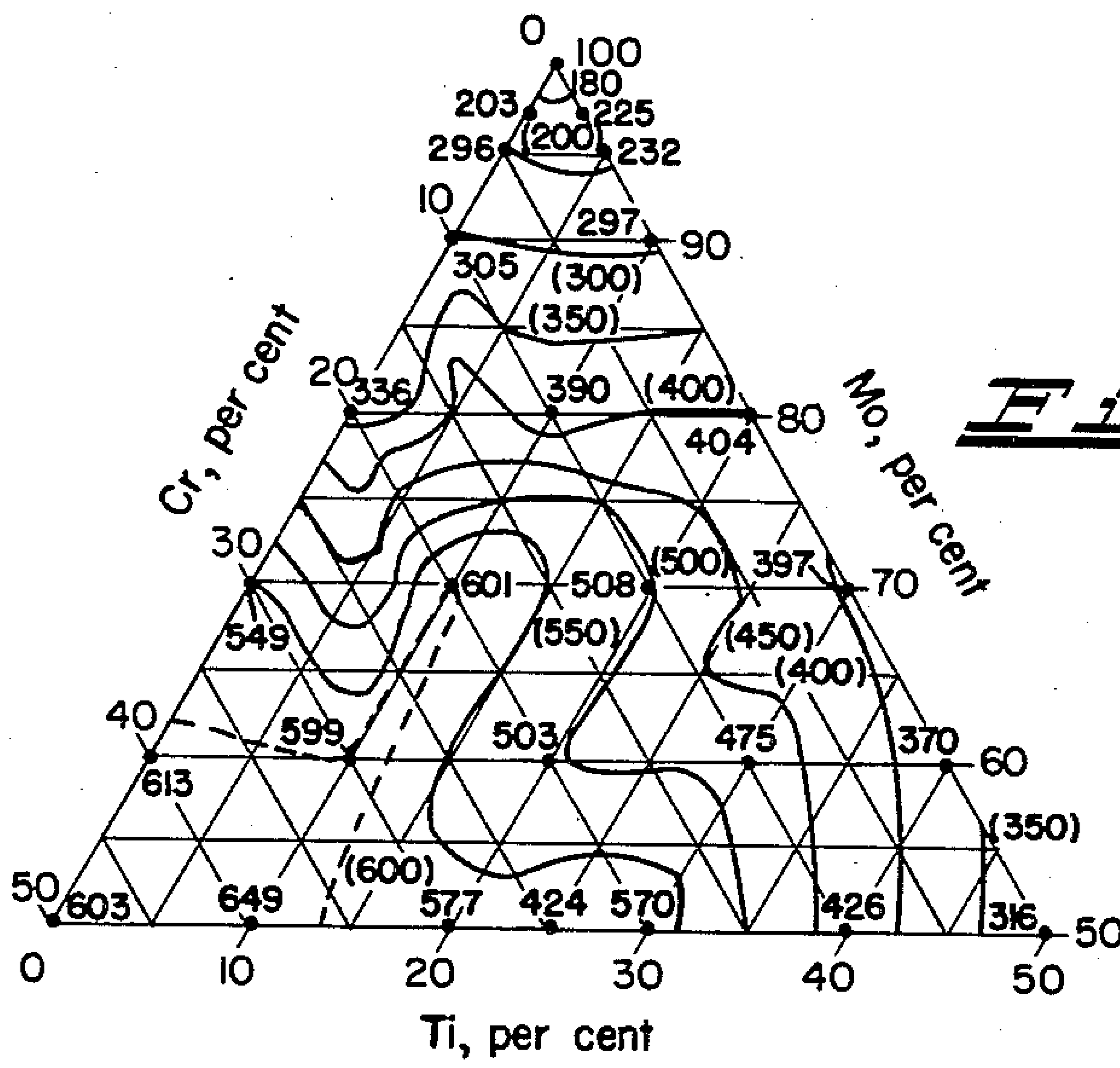


Fig. 4

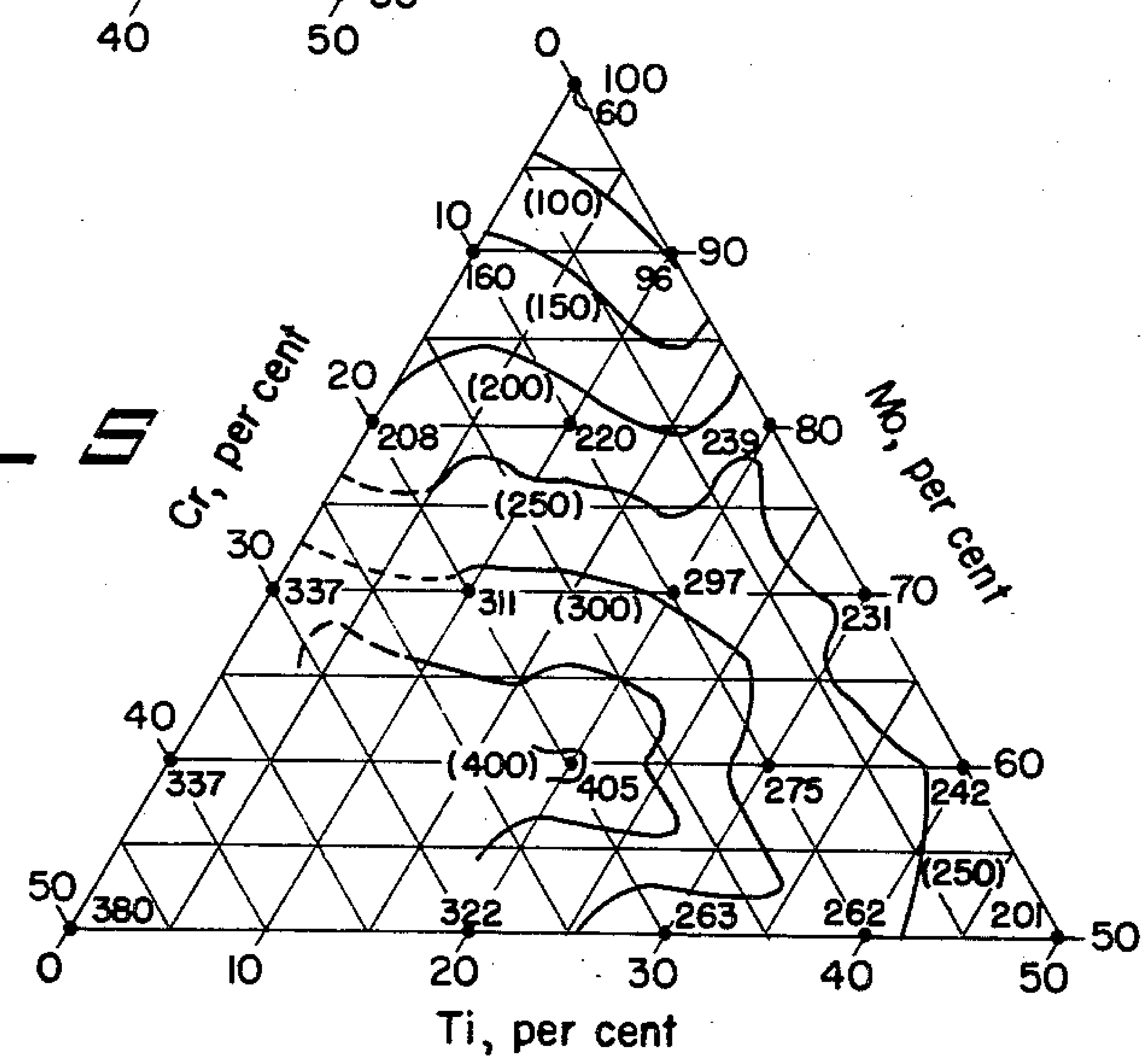


Fig. 5

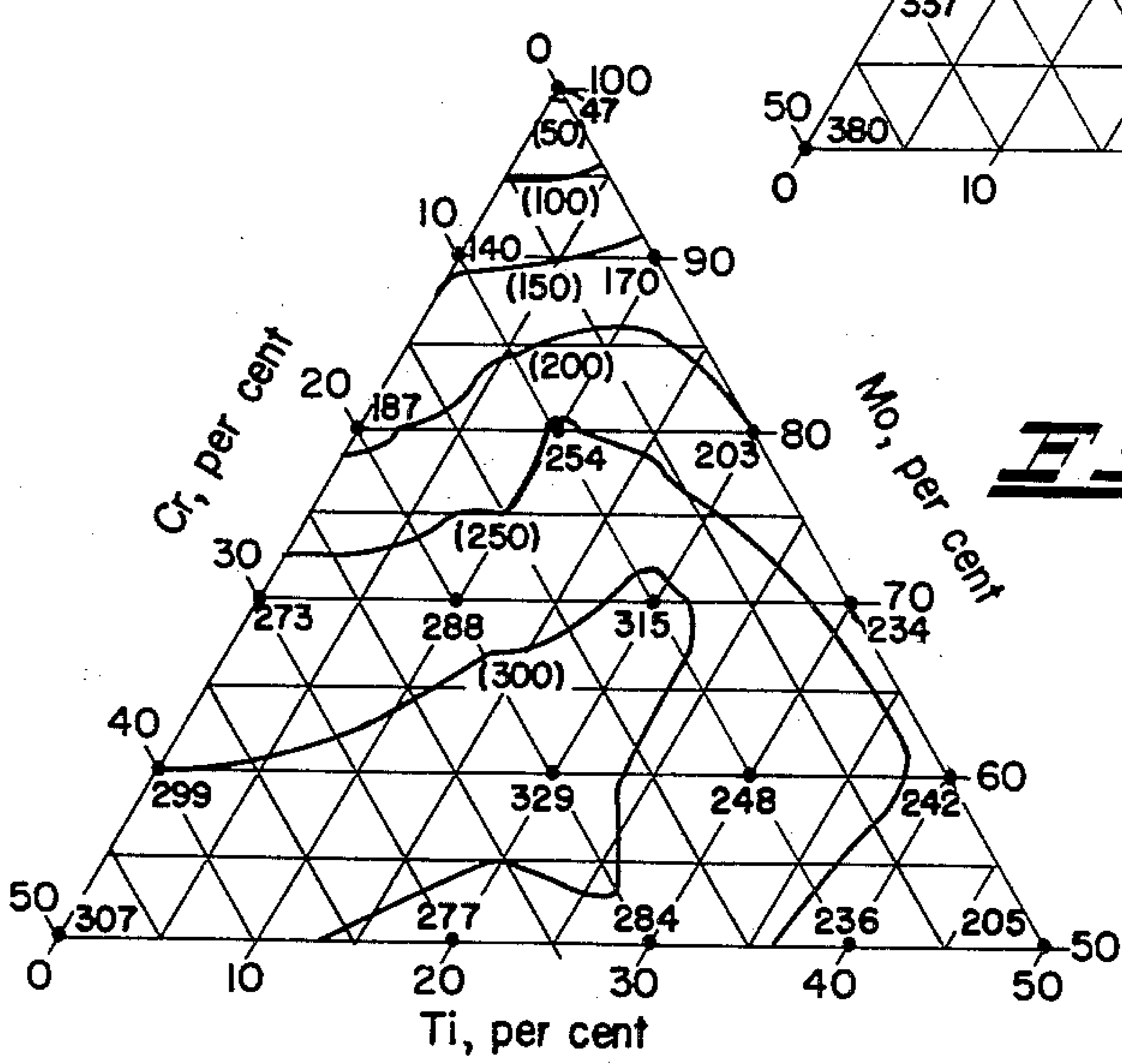


Fig. 6

INVENTOR.
James D. Nisbet

BY Gray, Mase & Dunson
ATTORNEYS.

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MOLYBDENUM-BASE ALLOY
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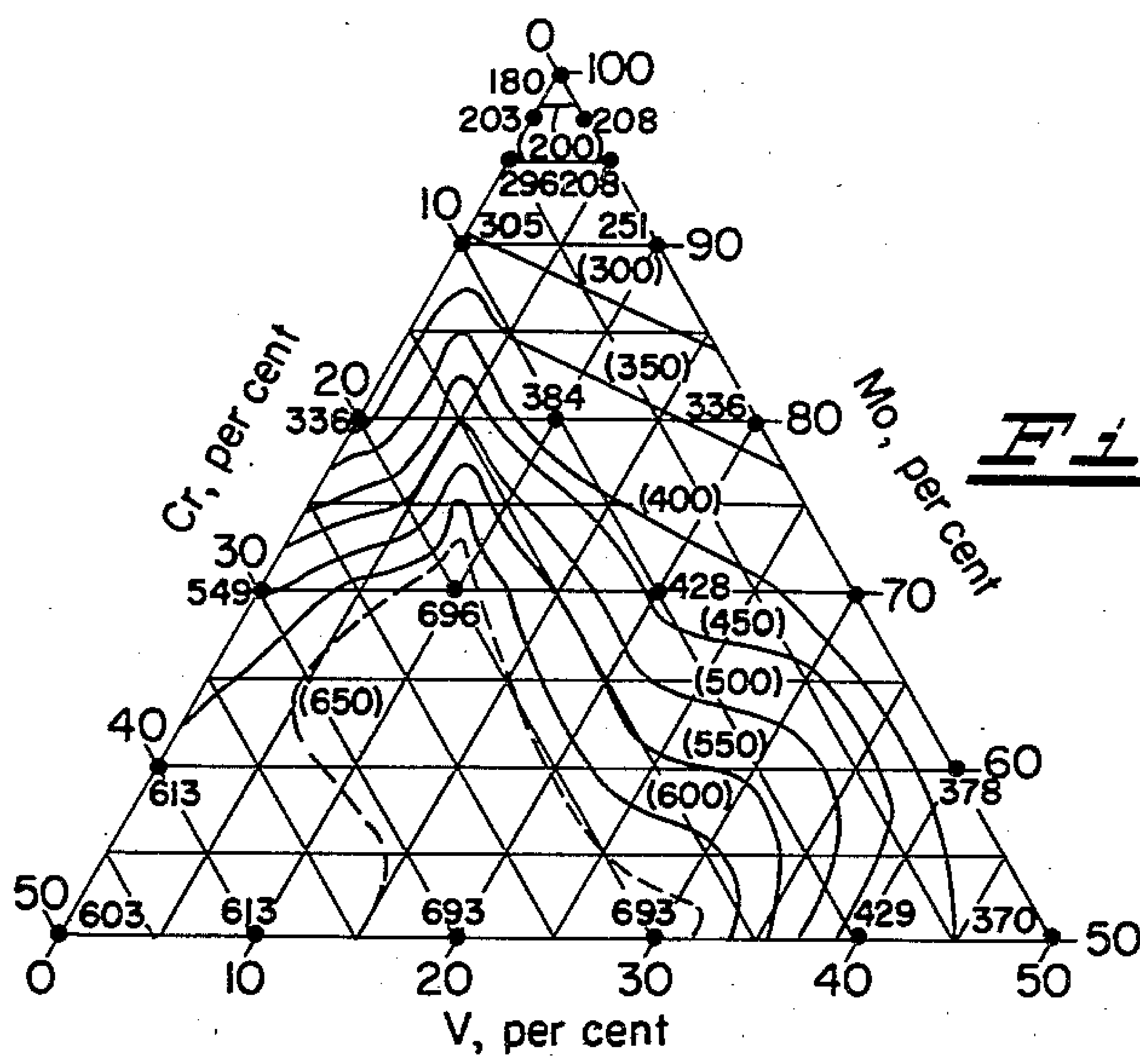

Fig. 7

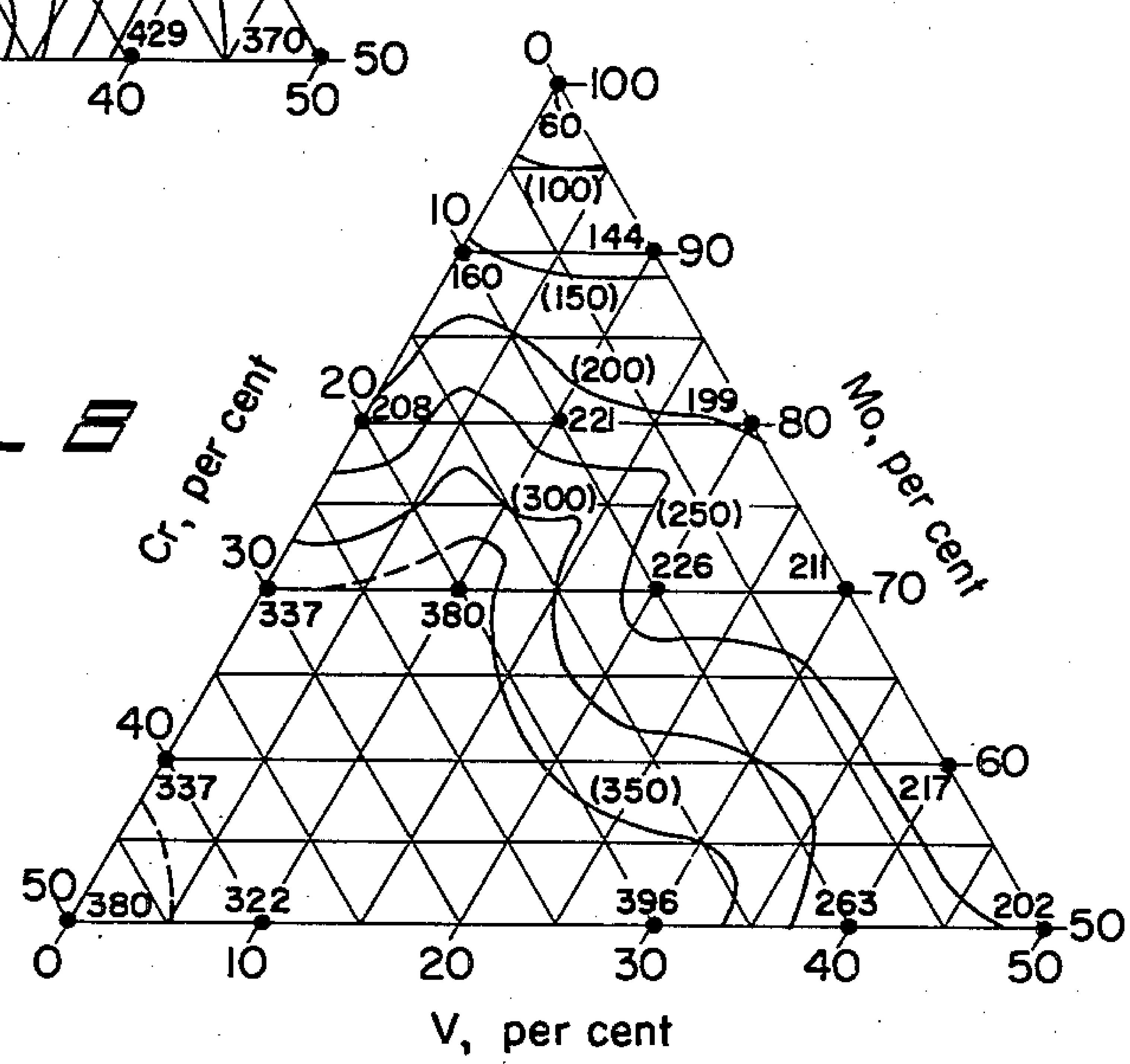

Fig. 8

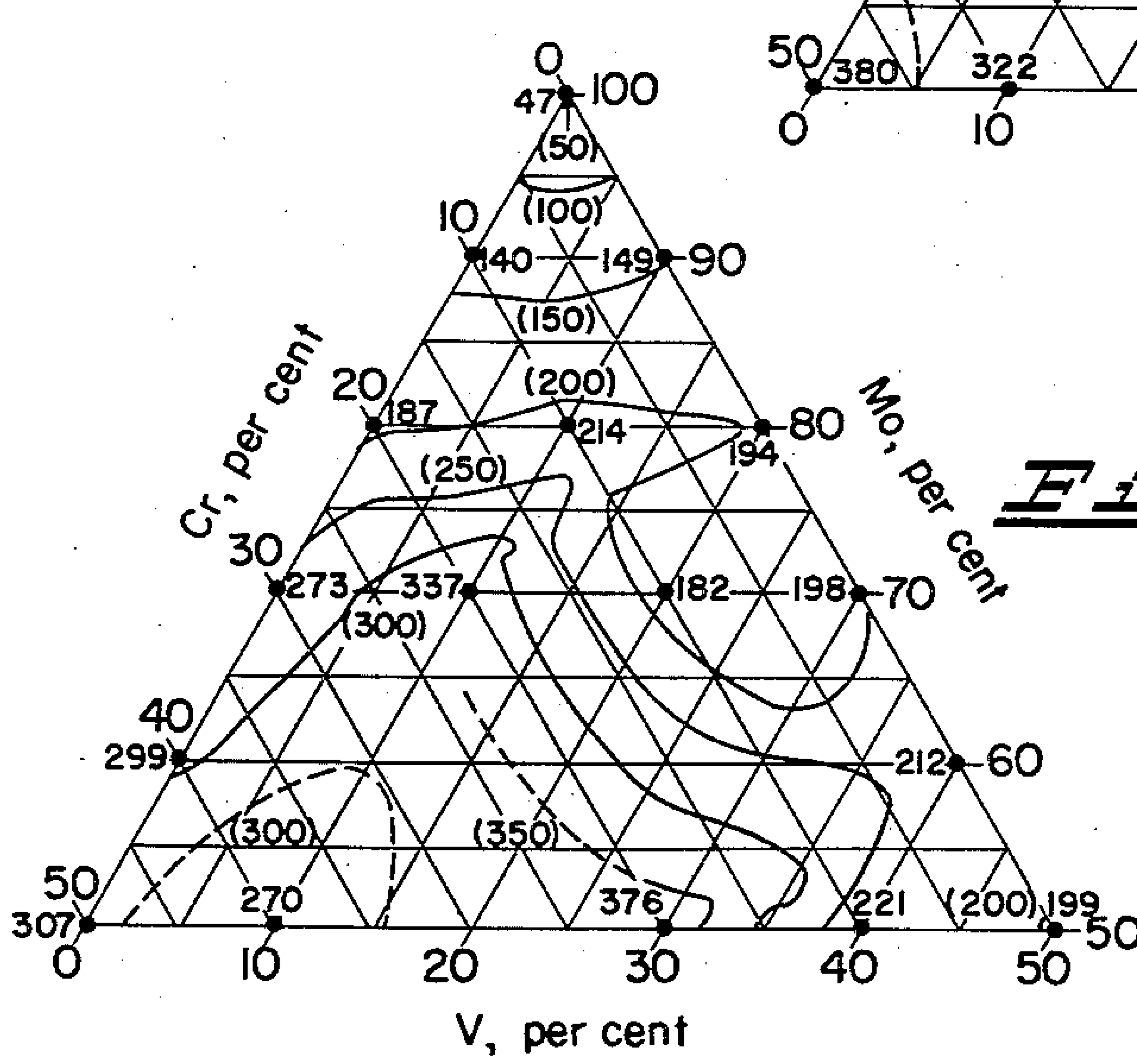

Fig. 9

INVENTOR.
James D. Nisbet
BY Gray, Mase & Dunson
ATTORNEYS.

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MOLYBDENUM-BASE ALLOY

James D. Nisbet, Pittsburgh, Pa., assignor to Universal-Cyclops Steel Corporation, Bridgeville, Pa., a corporation of Pennsylvania

Application August 29, 1955, Serial No. 531,056

6 Claims. (Cl. 75—176)

This invention relates to molybdenum-base alloys, and more specifically to molybdenum-base alloys which exhibit superior strength and hardness over a wide range of temperatures.

For a great variety of industrial and military applications, it is highly desirable to use metals that maintain their hardness and strength at elevated temperatures. For such applications as gas turbine components, jet engine parts, high-speed cutting tools and dies there is an ever-increasing demand for hard and strong metals and materials that will retain such hardness and strength at higher temperatures.

Although the alloys used today, such as the cobalt-chromium-nickel alloys for high-temperature, high-strength applications are far superior to metals once used for high-temperature applications, the increasing demands for harder and stronger metals for high-temperature applications make any advance in the art toward this goal highly significant.

The principal object of this invention is to provide improved cast alloys which exhibit high strength and hardness at both room and elevated temperatures.

Another object of this invention is to provide molybdenum-base alloys which retain high hardness at elevated temperatures.

Another object of this invention is to provide molybdenum-base alloys which will retain room-temperature hardness properties after being subjected to high temperatures.

Other objects and advantageous features will be obvious in the following specification and examples.

In accordance with the present invention binary, ternary and complex molybdenum-base alloys have been found that possess improved strength properties at elevated temperatures.

In general, this invention relates to molybdenum-base alloys containing at least one metal selected from the high-melting-point refractory metals from the IV–A, V–A, and VI–A atomic groups of the periodic table. Specifically, this invention relates to hard, high-melting-point alloys which possess high strength or hardness at room and elevated temperatures and which contain at least 50 percent molybdenum and at least one metal selected from the group tantalum, titanium, columbium, vanadium, tungsten, and chromium.

In the drawings:

Fig. 1 is a triaxial diagram on which is plotted compositions and hardness levels of binary and ternary molybdenum-base alloys containing vanadium and/or titanium. The hardnesses are room-temperature Vickers hardness numbers.

Fig. 2 is a triaxial diagram on which are plotted compositions of molybdenum-base alloys containing vanadium and/or titanium as in Fig. 1 but the Vickers hardness numbers of Fig. 2 are taken at 700° C.

Fig. 3 is a triaxial diagram on which are plotted compositions of molybdenum-base alloys containing vanadium

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and/or titanium as in Fig. 1 but the Vickers hardness numbers of Fig. 3 are taken at 900° C.

Fig. 4 is a triaxial diagram on which is plotted compositions and hardness levels of binary and ternary molybdenum-base alloys containing chromium and/or titanium. The hardnesses are room temperature Vickers hardness numbers.

Fig. 5 is a triaxial diagram on which are plotted compositions of molybdenum-base alloys containing chromium and/or titanium as in Fig. 4 but the Vickers hardness numbers of Fig. 5 are taken at 700° C.

Fig. 6 is a triaxial diagram on which are plotted compositions of molybdenum-base alloys containing chromium and/or titanium as in Fig. 4 but the Vickers hardness numbers of Fig. 6 are taken at 900° C.

Fig. 7 is a triaxial diagram on which is plotted compositions and hardness levels of binary and ternary molybdenum-base alloys containing chromium and/or vanadium. The hardnesses are room-temperature Vickers hardness numbers.

Fig. 8 is a triaxial diagram on which are plotted compositions of molybdenum-base alloys containing chromium and/or vanadium as in Fig. 7 but the Vickers hardness numbers of Fig. 8 are taken at 700° C.

Fig. 9 is a triaxial diagram on which are plotted compositions of molybdenum-base alloys containing chromium and/or vanadium as in Fig. 7 but the Vickers hardness numbers of Fig. 9 are taken at 900° C.

In the drawings, the top or uppermost point of the triaxial diagram represents 100 percent molybdenum, while the base of the diagram represents 50 percent molybdenum. Alloying metals are designated for each side of the diagrams. The composition of any point on the diagram may be determined by reading molybdenum content from the bottom to the top at 10 percent intervals, as indicated. Alloying metal contents are determined by projecting a line from the point to the side of the diagram representing such addition, parallel to the lines projecting beyond the diagram and read at 10 percent intervals, as indicated. For example, in Fig. 1 titanium content is determined by projecting a line to the bottom of the diagram, as indicated, parallel to the lines extending slightly below the diagram at the bottom and read from left to right. Vanadium content is determined in the same manner as the titanium content but read along the left side of the diagram, as indicated. The points which are marked and Vickers hardness numbers given are actual examples produced in the laboratory and charted on the diagrams. The solid lines are contour lines designating levels of hardness and the circled numbers indicate the hardness levels by Vickers hardness numbers.

Molybdenum-base binary alloys, containing as the alloying addition, titanium, vanadium, chromium, columbium or tantalum have been found to have excellent high-strength or hardness properties at both room temperature and at elevated temperatures. In a like manner, ternary alloys containing at least 50 percent molybdenum and at least two metals selected from the group titanium, vanadium, chromium, tungsten, columbium, and tantalum have been found to have equal or superior strength to the binary system.

Alloys which are suitable for applications such as high-speed cutting tools, dies, jet engine parts, and gas-turbine components preferably have a room-temperature hardness of at least 300 Vickers hardness number and for high-temperature applications a hardness of at least 150 Vickers hardness number. Table I below illustrates the minimum binary alloying additions to molybdenum which will result in minimum room-temperature hardnesses of at last 300 Vickers hardness number and at least 150 Vickers hardness number at a temperature of 700° C.

Table I

	Percent
Titanium	15
Vanadium	15
Chromium	15
Columbium	15
Tantalum	20

It is further illustrated by Figs. 1 through 9 and Table II that ternary alloys containing at least 50 percent molybdenum and at least one of any of the above binary additions to molybdenum will present high strength properties.

The properties of three of the binary and three of the ternary alloys are clearly illustrated in Figs. 1 through 9. The range of molybdenum-titanium-vanadium alloys possessing room-temperature hardnesses in excess of 300 Vickers hardness number and 150 Vickers hardness number at 700° C. are clearly illustrated in Table II and Figs. 1 and 2. These ternary alloy compositions are shown in Fig. 2 by all of the compositions falling below the 150 Vickers hardness number level. The range of molybdenum-titanium-chromium alloys possessing room-temperature hardnesses in excess of 300 Vickers hardness number and 150 Vickers hardness number at 700° C. are clearly illustrated in Figs. 4 and 5. These ternary alloy compositions are shown in Fig. 5 by all the compositions falling below the 150 Vickers hardness number level. The range of molybdenum-vanadium-chromium alloys possessing room-temperature hardnesses in excess of 300 Vickers hardness number and 150 Vickers hardness number at 700° C. are clearly illustrated in Figs. 7 and 8. These ternary alloy compositions are shown in Fig. 8 by all the compositions falling below the 150 Vickers hardness number level line.

In a similar manner, ternary alloys including at least two of the binary additions described above will provide room-temperature hardnesses in excess of 300 Vickers hardness number and high-temperature properties of at least 150 Vickers hardness number at 700° C.

Alloys containing more than 50 percent alloying additions to molybdenum are outside the range of the alloys disclosed and are no longer molybdenum-base alloys. Strength properties generally fall off as the alloying content increases beyond 50 percent. The molybdenum content is, therefore, preferably a minimum of 50 percent by weight of the alloy.

Tungsten may be alloyed to molybdenum as a ternary or complex alloying addition falling within the scope of the present invention, so long as the strength properties at room and elevated temperatures are not adversely affected. For examples, as may be noted by referring to Table II, binary molybdenum-tugsten alloys possess hardnesses far below 150 Vickers hardness number at a temperature of 700° C., therefore, binary molybdenum-tungsten alloys do not fall in the scope of the present invention. Also, as exemplified by Table II, ternary molybdenum-tungsten alloys may possess sufficient hardness properties to fall within the scope of the present invention. However, the alloys of the present invention contain at least 50 percent molybdenum. As can be seen in Table II, large additions of tungsten may be made while retaining high hardness.

It can be seen from Figs. 3, 6, and 9 that there are also optimum ranges for certain molybdenum-base ternary alloys. These alloys exhibit a minimum of hardness of 250 Vickers hardness number at 900° C. Though the alloys of this invention retain, to a remarkable extent, their hardness at elevated temperatures, there is, of course, some hardness drop-off as the temperature rises. Although hardnesses of 150 Vickers at temperatures as high as 700° C. are useful high-temperature properties, it is felt that hardnesses of 250 Vickers at temperatures of 900° C. are of much greater significance. Such high-temperature hardness and strength render these alloys within the optimum composition ranges, ideal materials

for high-temperature applications where high-strength properties are required. Compositions exhibiting 250 Vickers or greater hardness at 900° C. are set forth in Figs. 3, 6, and 9 of the accompanying diagrams within the 250 Vickers hardness number levels.

Microscopic studies show that molybdenum-base alloys containing titanium, vanadium, tantalum, columbium, chromium and tungsten are all single phase solid solution alloys. The alloys discussed so far are, therefore, the solid solution type of alloys which exhibit solid solution strength properties.

It has been found that improved room and elevated temperature strength properties may be attained by alloying zirconium with the other molybdenum-base alloys of the present invention. The addition of zirconium to molybdenum or molybdenum-base alloys results in microscopic structures composed of a terminal solid-solution phase of zirconium in molybdenum and the intermetallic compound $ZrMo_2$. The difficulty experienced with this type of alloy is the complete lack of workability of the metal at either room or elevated temperatures, however, it has been found that small additions of zirconium to the above binary or complex alloys may be satisfactorily employed to attain improved strength properties while retaining the required degree of workability necessary to be adapted to high-temperature applications. The small additions of zirconium to the terminal solid-solution phase molybdenum-base alloys which may be employed to attain the room and high temperature strength properties of the present invention while maintaining adequate workability is from about 2 to 10 percent.

Examples of binary molybdenum-zirconium alloys given in Table II illustrate the extreme hardness of the binary alloy.

It is obvious that combinations including any of the alloying additions to molybdenum of this invention can be made to form alloys containing three and even four alloying elements, without departing from the scope of this invention.

The molybdenum-base alloys of the present invention were arc-melted using a water-cooled hearth. A very pure helium atmosphere at low pressures (10 to 20 cm. of mercury pressure) was employed. By using a pure helium atmosphere, little or no oxygen pickup was experienced so that it was not necessary to add deoxidants such as carbon, aluminum, or boron to the melts. It should be noted that additions of such elements as carbon, aluminum, or boron generally harden the metal to some extent.

Table II below covers all the ranges disclosed above, illustrates specific examples of the molybdenum-base alloys of this invention and shows their strength properties at various elevated temperatures.

Table II

Composition, weight percent (balance Mo)	Vickers hardness number				
	25° C.	300° C.	500° C.	700° C.	900° C.
Mo (unalloyed)	180	80	74	60	47
2.5 Ti	225	----	----	----	----
5 Ti	232	----	----	----	----
10 Ti	279	211	155	96	170
20 Ti	404	292	242	239	203
30 Ti	397	288	250	231	234
40 Ti	370	303	254	242	242
50 Ti	316	236	225	201	205
2.5 V	208	----	----	----	----
5 V	208	----	----	----	----
10 V	251	178	151	144	149
20 V	336	248	197	199	194
30 V	384	257	228	211	198
40 V	378	268	239	217	212
50 V	370	222	228	202	199
2.5 Cr	203	----	----	----	----
5 Cr	296	----	----	----	----
10 Cr	305	202	165	160	140
20 Cr	336	260	231	208	187
30 Cr	549	462	375	337	273
40 Cr	613	506	412	337	299
50 Cr	603	418	389	380	307
2.5 Cb	201	----	----	----	----

Table II.—Continued

Composition, weight percent (balance Mo)	Vickers hardness number				
	25° C.	300° C.	500° C.	700° C.	900° C.
5 Cb	220	----	----	----	----
10 Cb	269	173	154	132	134
20 Cb	324	218	198	174	167
30 Cb	397	265	233	211	----
40 Cb	431	275	267	250	250
50 Cb	476	284	286	278	267
2.5 Ta	207	----	----	----	----
5 Ta	206	----	----	----	----
10 Ta	231	137	107	96	108
20 Ta	302	191	181	150	168
30 Ta	343	259	220	199	220
40 Ta	396	275	244	242	234
50 Ta	459	286	253	223	234
10 Ti–10 V	451	284	256	229	235
20 Ti–10 V	440	315	282	270	235
10 Ti–20 V	459	250	233	216	239
30 Ti–10 V	417	----	----	----	----
10 Ti–30 V	497	----	----	----	----
40 Ti–10 V	380	----	----	----	----
10 Ti–40 V	387	----	----	----	----
20 Ti–20 V	432	322	299	259	254
30 Ti–20 V	424	234	218	201	185
20 Ti–30 V	439	----	----	----	----
10 Ti–10 Cr	390	270	235	220	254
20 Ti–10 Cr	508	357	352	297	315
10 Ti–20 Cr	601	379	329	311	288
30 Ti–10 Cr	475	286	277	275	248
10 Ti–30 Cr	599	----	----	----	----
40 Ti–10 Cr	426	297	259	262	236
10 Ti–40 Cr	649	----	----	----	----
20 Ti–20 Cr	503	383	379	405	329
20 Ti–30 Cr	570	379	379	322	277
30 Ti–20 Cr	577	370	383	263	284
10 Cr–10 V	384	247	248	221	214
20 Cr–10 V	696	437	398	380	337
10 Cr–20 V	428	247	190	226	182
40 Cr–10 V	613	288	250	322	270
10 Cr–40 V	429	290	271	263	221
30 Cr–20 V	693	----	----	----	----
20 Cr–30 V	693	516	456	396	376
25 Cr–25 Cb	645	----	----	----	----
25 Cr–25 Ta	371	----	----	----	----
25 Cr–25 Ti	424	----	----	----	----
25 Cb–25 Ta	435	----	----	----	----
25 Cb–25 Ti	414	----	----	----	----
25 Cb–25 W	393	----	----	----	----
25 Ta–25 Ti	425	----	----	----	----
25 Ta–25 V	473	----	----	----	----
25 Ta–25 W	361	----	----	----	----
25 Ti–25 W	427	----	----	----	----
25 V–25 W	372	----	----	----	----
10 W	213	93	71	71	63
20 W	208	106	97	90	84
30 W	213	106	76	71	71
40 W	242	111	108	94	89
50 W	244	159	127	106	77
1 Zr	208	----	----	----	----
2.5 Zr	314	----	----	----	----
5 Zr	384	----	----	----	----
7.5 Zr	363	----	----	----	----
10 Zr	519	----	----	----	----

What is claimed is:

1. An alloy consisting essentially of at least 50 percent molybdenum, and two metals selected from the group consisting of 10 to 40 percent tungsten, 10 to 40 percent titanium, 10 to 40 percent vanadium, 10 to 40 percent chromium, 10 to 40 percent columbium, and 10 to 40 percent tantalum, and characterized by high strength properties.

2. Alloys consisting essentially of at least 50 percent molybdenum, from 10 to 40 percent titanium, from 10 to 40 percent vanadium, and characterized by higher strength properties than binary molybdenum-titanium and molybdenum-vanadium alloys.

3. Alloys consisting essentially of at least 50 percent molybdenum, from 10 to 40 percent titanium, and from 10 to 40 percent chromium.

4. Alloys consisting essentially of at least 50 percent molybdenum, from 10 to 40 percent chromium, and from 10 to 40 percent vanadium.

5. Alloys consisting essentially of at least 50 percent molybdenum, from 10 to 40 percent chromium, and from 10 to 40 percent tantalum.

6. Alloys consisting essentially of at least 50 percent molybdenum, from 10 to 40 percent chromium, and from 10 to 40 percent tungsten.

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