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TENSILE AND IMPACT PROPERTIES OF SOME MARAGING STEEL COMPOSITIONS

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ABSTRACT

Laboratory vacuum induction heats of 18%-Ni maraging steels were cast into 25-pound ingots and forged into flat bar stock. Transverse tensile and Charpy V specimens were obtained from the forged material. One composition contained 8.4% Co, 3.2% Mo, and 0.2% Ti; five others contained 7% or 9% Co and 3.2%, 3.8%, or 5% Mo, but no titanium. Specimens were aged at various temperatures up to 1000°F, and Charpy V and tensile properties were determined at room temperature. Charpy V tests were also conducted at 30° and -20°F. The titanium-containing composition consistently developed considerably better combinations of Charpy V toughness and yield strength than did the others. When aged at 900°F the yield strength was 190,500 psi, and the Charpy V impact energy level in the temperature range -20° to 80°F exceeded 50 foot-pounds. Aging at lower temperatures resulted in greater toughness and lower yield strengths.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

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INTRODUCTION

The maraging steels are a recently developed class of virtually carbon-free steels which may be heat treated to high strength levels by aging at moderate temperatures (1,2). When air-cooled from temperatures of the order of 1500°F after hot working or annealing, for instance, the steels have a structure of comparatively soft, cubic martensite and can be readily cold worked or machined. On subsequent aging at temperatures up to 1000°F, precipitation and ordering processes occur which result in the hardening of the metal to strength levels which depend upon composition and aging time and temperature.

The class of maraging steels comprises a considerable variety of compositions, but, so far, most attention has been paid to the subclass containing about 18% nickel together with cobalt, molybdenum, and titanium, and particularly to those compositions capable of developing yield strengths in the range 250,000 to 300,000 psi when aged at 900°F (3). While these compositions have good toughness by comparison with that of other materials at comparable strength levels, this degree of toughness is inadequate for certain rigorous applications, such as submarine hulls. For such applications it is necessary to seek other compositions of this class of steels which would have greater toughness combined with yield strengths in the range 150,000 to 200,000 psi. The question of what constitutes adequate toughness for submarine hull applications is one which is currently under intensive investigation; however, there are strong indications that a Charpy V shelf-energy level of 50 foot-pounds is a conservative criterion for preliminary screening purposes (4). Since very little information is available on the properties of maraging steels at these relatively low strength levels, it was considered desirable to produce and test a series of appropriate compositions.

The first group of these compositions, with which this report is solely concerned, are simplified variants of a composition which is recommended for use at the 200,000-psi yield strength level (5). The nominal composition of the 200,000-psi-recommended material is: 18% Ni, 8.5% Co, 3.2% Mo, and 0.2% Ti. All other elements, particularly C, Si, Mn, S, and P, are kept to very low levels. Also, small amounts of Al, B, and Zr are deliberately added as being beneficial in the quantities used (1).

Of the seven heats discussed in this report, one had essentially the given nominal composition, but no additions of Al, B, or Zr were made. The other six heats differed from the nominal composition in that they contained no titanium. Although titanium is a secondary strengthening agent in the maraging steels, it is not essential for the development of high strength levels. In certain kinds of welding, accurate control of the titanium content of the deposit could constitute a problem. For this reason, it is of interest to know whether titanium-free maraging steels might be suitable for applications in the 150,000 to 200,000-psi yield strength range. The variable factors in these six titanium-free compositions are the cobalt and molybdenum contents.

The effect of aging temperature on the tensile properties and Charpy V impact energy was investigated for each composition. Although it is usually recommended that maraging steels should be aged at 900°F to develop the maximum yield strengths of which they are capable, there is no obvious reason why a different aging temperature might not result in a more appropriate balance of strength and toughness for a given application. For applications such as submarine hulls there are obvious practical reasons for preferring a lower aging temperature, if feasible.

MATERIALS AND PROCEDURE

Ingots of the required compositions were produced by vacuum induction melting of charges made up of high-purity, vacuum-melted iron and high-purity nickel, cobalt, molybdenum, and titanium. Each 25-pound heat was poured into an ingot of approximately 3-in.-square cross section. The analyzed compositions of the steels are given in Table 1. The major part of each ingot was hammer-forged in the temperature range 1500° to 2200°F into 0.5 by 2.5-in.-section bar stock. This was subsequently cut up into transverse Charpy specimen blanks. The remaining portion of each ingot was forged into 0.6 by 3.0-in.-section bar stock to be cut up into transverse tensile specimen blanks. All specimen blanks were solution annealed at 1500±10°F for one hour and air-cooled before machining. The orientation of the Charpy specimens with respect to the bar stock was such that the notched faces were perpendicular to the 2.5-in.-wide surfaces of the bar. This orientation would be expected to provide the most severe test of the toughness since the fracture in the Charpy specimen would propagate in the comparatively weak direction of major forging flow.

Table 1
Analyses of the Steels

Heat Number	Composition (wt-%)									
	C	Mn	S	P	Si	Ni	Co	Mo	Ti	Al
276	0.02	0.00	0.003	0.002	0.00	18.5	7.0	3.8	0.00	0.01
277	0.03	0.00	0.005	0.003	0.00	18.5	9.0	3.8	0.00	0.01
278	0.02	0.00	0.004	0.003	0.00	18.5	7.0	5.0	0.00	0.01
279	0.02	0.00	0.004	0.004	0.00	18.5	9.0	5.0	0.00	0.01
283	0.02	0.00	0.006	0.002	0.00	18.3	0.01	3.4	0.00	0.01
284	0.02	0.00	0.004	0.002	0.00	18.5	8.8	3.2	0.00	0.01
285	0.02	0.00	0.005	0.002	0.00	18.5	8.4	3.2	0.20	0.01

After machining to size, sets of three Charpy and one tensile specimens of each composition were aged for 3 hours at each of the following temperatures: 400°, 500°, 600°, 700°, 800°, 900°, and 1000°F. The tensile specimen (0.252-in. diam) and one of the Charpy specimens from each set were tested at room temperature. The other Charpy specimens were tested at 20° or -30°F. An additional set of each composition was tested in the unaged condition.

DISCUSSION OF RESULTS

The results of the tensile tests at 80°F are given in Table 2, and those of the Charpy tests are given in Table 3. The yield strengths are plotted versus aging temperature in Figs. 1 and 2, the curves being separated into two figures to avoid confusion. Yield strengths in the unaged condition are not shown since they differed little from those for the 400°F aged condition.

Table 2
Tensile Properties at 80°F

Heat Number	Aging Temp.* (°F)	Tensile Strength (ksi)	Yield Strength (ksi)	Reduction of Area (%)	Elongation on 1 in. (%)
276	Not Aged	134.5	104.5	70.0	18.0
	400	130.0	104.0	72.0	18.0
	500	131.0	111.5	66.5	17.0
	600	139.0	117.5	65.0	18.0
	700	147.2	127.0	66.5	17.0
	800	155.0	140.0	52.0	17.0
	900	182.5	172.0	53.6	15.0
	1000	184.0	162.5	54.6	19.0
277	Not Aged	135.0	106.0	62.8	17.0
	400	136.0	103.0	64.5	17.0
	500	138.5	114.5	61.3	15.0
	600	146.0	124.0	61.5	18.0
	700	165.5	149.0	56.8	17.0
	800	175.5	162.0	57.3	15.0
	900	202.0	190.0	51.4	13.0
	1000	195.0	174.0	53.0	19.0
278	Not Aged	132.0	101.0	72.2	18.0
	400	136.5	108.5	71.8	17.0
	500	140.0	116.0	70.1	17.0
	600	147.5	127.5	66.0	18.0
	700	166.0	147.0	63.5	18.0
	800	172.0	158.0	56.6	17.0
	900	212.0	194.0	48.0	12.0
	1000	203.5	179.0	54.8	18.0
279	Not Aged	134.0	97.5	70.0	18.0
	400	137.5	109.5	67.0	17.0
	500	140.0	116.5	68.0	17.0
	600	151.0	128.0	62.8	17.0
	700	182.5	163.5	59.5	19.0
	800	218.0	203.0	52.0	15.0
	900	217.0	207.0	55.0	14.0
	1000	212.0	187.0	53.5	18.0
283	Not Aged	125.2	108.0	68.7	16.0
	400	125.5	105.5	68.0	16.0
	500	125.2	109.4	68.8	18.0
	600	128.0	110.2	69.5	20.0
	700	129.0	114.5	68.0	20.0
	800	126.2	116.1	68.6	22.0
	900	130.0	124.0	68.5	21.0
	1000	133.0	118.5	65.5	23.0
284	Not Aged	131.0	111.0	68.0	16.0
	400	132.5	108.0	71.0	17.0
	500	133.5	113.0	70.1	18.0
	600	141.0	123.0	66.5	20.0
	700	154.5	138.0	68.2	23.0
	800	161.0	150.0	67.0	19.0
	900	183.0	164.5	64.8	16.0
	1000	179.5	171.0	65.2	22.0
285	Not Aged	134.5	113.8	77.5	19.0
	400	135.0	114.0	73.0	18.0
	500	137.8	120.5	75.6	20.0
	600	144.5	126.5	72.5	20.0
	700	162.5	143.5	66.5	21.0
	800	174.5	163.0	68.6	21.0
	900	199.0	190.5	68.1	16.0
	1000	195.0	185.0	65.2	19.0

*Aging Time: 3 hours.

Table 3
Charpy V Impact Energies

Heat Number	Aging Temp.* (°F)	Charpy V Energy (ft-lb) At 80°F	At 30°F	At -20°F
276	Not Aged	51	62	47
	400	45	43	37
	500	65	42	46
	600	51	44	40
	700	37	34	37
	800	38	36	36
	900	29	32	29
	1000	26	29	21
277	Not Aged	74	73	57
	400	90	84	64
	500	78	86	91
	600	68	56	50
	700	37	35	35
	800	41	39	38
	900	27	26	26
	1000	29	29	28
278	Not Aged	72	64	60
	400	96	90	85
	500	98	78	86
	600	57	74	51
	700	42	39	38
	800	42	40	37
	900	24	23	18
	1000	32	25	29
279	Not Aged	90	78	73
	400	86	55	49
	500	70	76	60
	600	42	45	39
	700	30	32	30
	800	26	26	24
	900	21	21	23
	1000	22	22	20
283	Not Aged	81	96	86
	400	54	94	84
	500	97	49	79
	600	98	108	108
	700	57	53	64
	800	77	24	48
	900	27	50	43
	1000	52	50	54
284	Not Aged	96	126	120
	400	97	103	117
	500	90	107	130
	600	100	100	124
	700	90	105	62
	800	110	70	59
	900	45	40	35
	1000	46	40	37
285	Not Aged	149	144	140
	400	145	136	153
	500	142	143	160
	600	136	140	132
	700	88	87	88
	800	69	76	70
	900	52	68	58
	1000	58	56	50

*Aging Time: 3 hours.

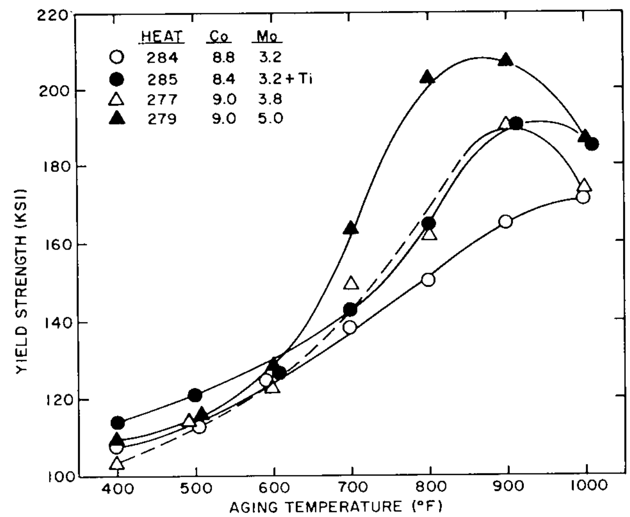

Fig. 1 - Yield strengths vs aging temperature for the four compositions containing more than 8% Co. The specimens were aged for 3 hours at the indicated temperatures.

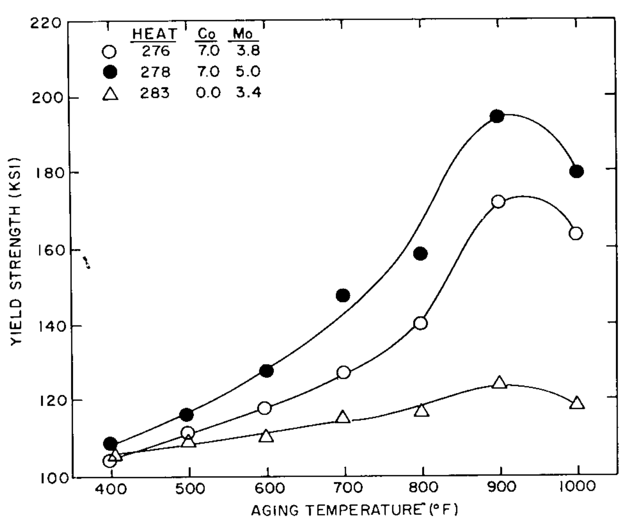

Fig. 2 - Yield strength vs aging temperatures for the three compositions containing less than 8% Co. The specimens were aged for 3 hours at indicated temperatures.

The four steels represented in Fig. 1 are the three which had 9% Co with different levels of Mo, and the recommended composition containing 0.2% Ti. Aging at temperatures below 700°F had only a moderate effect, and the different compositions do not differ much in yield strength when aged at these temperatures. The effect of composition becomes evident at higher aging temperatures. The maximum yield strength is greater and occurs at a lower aging temperature as the molybdenum content in the titanium-free alloys becomes greater. The aging curve of the titanium-containing composition, heat 285, follows fairly closely that of the titanium-free composition, heat 277, which contained 3.8% Mo. Presumably the 0.2% Ti of heat 227 just about compensated for the lower Co and Mo contents of heat 285. However, heat 285 had a substantially higher yield strength when aged at 1000°F than did heat 277, indicating the tendency of titanium to inhibit overaging.

The remaining three steels, represented in Fig. 2, are the two which had 7% Co with 3.8% or 5.0% Mo, and the one which contained 3.4% Mo and no cobalt. The latter responded only slightly to aging and need not be considered further. The aging curve of the higher molybdenum alloy, heat 278, is very similar to that of the titanium-containing alloy, heat 285, shown in Fig. 1. Comparison of the curves for heats 276 and 278 shows that the effect of molybdenum in the 7%-Co compositions is quite similar to the effect in the 9%-Co compositions.

As indicated in the Introduction, Charpy V impact energy values provide preliminary guidance as to the suitability, with respect to toughness, of materials for such applications as submarine hulls. Study of the values given in Table 3 will show that in no case is there a clear indication of a transition temperature occurring within the test temperature range 80° to -20°F. In many cases the three values at three different testing temperatures are in quite close agreement. Thus, the temperature range of service interest appears to be a range of substantially constant toughness for all compositions and aging temperatures considered here. This range could be either above or below a transition temperature, but where the impact energy level exceeds 50 foot-pounds the temperature range is unlikely to be below a transition temperature.

The various compositions are most conveniently compared by means of the plot shown in Fig. 3 where the Charpy V impact energies at -20°F are plotted versus yield strength. It is clear from this plot that the Charpy V energy in each case decreases continually as the yield strength increases, the greatest rate of decrease occurring at the lower levels of yield strength. However, at any given yield strength level the impact energy depends upon the composition and is always greater for heat 285, the recommended titanium-bearing composition, than for any of the others. Furthermore, even at its maximum yield strength of 190,500 psi, the impact energy level for this steel exceeded 50 foot-pounds, suggesting good promise of adequate toughness for submarine hull applications. The impact energy level for the best of the titanium-free compositions, heat 284, dropped below 50 foot-pounds at a yield strength somewhere between 150,000 and 165,000 psi.

CONCLUSIONS

The results show clearly that the titanium-containing composition (heat 285) developed considerably better combinations of yield strength and Charpy V toughness than did the titanium-free compositions (Fig. 3). This composition is essentially that recommended by the original developers of maraging steels for applications at a yield strength level of 200,000 psi. When specimens of this composition were aged for 3 hours at 900°F, the yield strength was 190,500 psi and the Charpy V impact energy level in the temperature range -20° to 80°F somewhat exceeded 50 foot-pounds. This is considered to indicate good promise of adequate toughness for submarine hull applications and would justify extensive further testing by drop-weight-tear and explosion-tear methods (4).

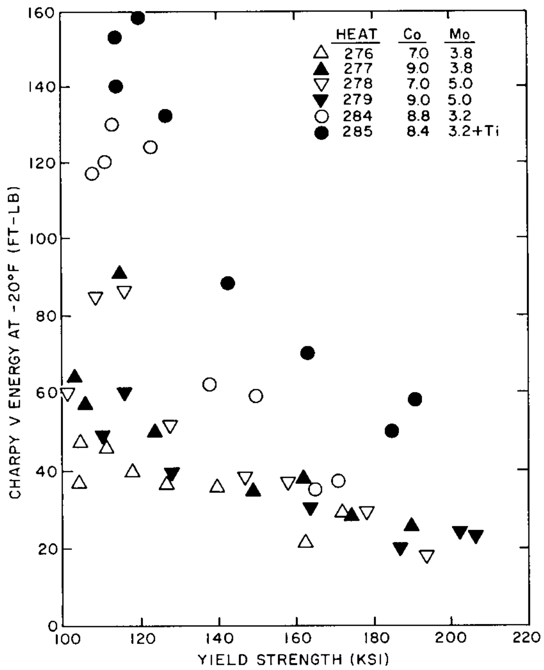

Fig. 3 - Charpy V impact energy at -20°F vs yield strength for the six compositions which responded to aging

Aging at lower temperatures than 900°F resulted in greater toughness and lower yield strengths. For some applications the combination resulting from a lower temperature aging treatment might be preferred.

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