THE APPLICATION OF ALLOY AND SPECIAL STEELS IN RAILWAY WORK

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MANY people are concerned about the conservation of metal, especially in these days when such things as tin cans, razor blades, etc., cause steel to disappear from the recovery cycle. The intelligent use of alloy steels may help in this conservation, provided that they are not employed in a profligate manner and that alloy elements are not allowed to go to waste in slags. Manganese is one of the most useful elements in steel manufacture, and the present consumption is said to average about 14 lb. Mn per ton of ingots[1]. When steel scrap is remade into ingots, much of this element is lost by oxidation, and already there is anxiety about manganese conservation. Steel melting processes which would avoid the removal of most of the manganese from the charge are, therefore, to be welcomed, and one attempt to operate a simple fusion process for fine grain castings has been described[2]. Where current is cheap, it is possible that this objective may be achieved in electric furnaces.

In railway work the extra cost of alloy and special steels compared with plain carbon material must pay for itself by one or more of the following factors:

(a) weight reduction of mobile units
(b) reduced weight of reciprocating parts of locomotives
(c) increased resistance to wear and abrasion
(d) increased resistance to corrosion
(e) protection against service shock and impact
(f) increased endurance (fatigue) limit
(g) avoidance of cracking during heat treatment or heating in service
(h) efficient scrap recovery.

The general feature of alloy elements in steels is that during heat treatment they slow down the transformation of austenite to other microstructures, and thus enable hardening and strengthening effects to be sustained right through a large section of metal. If carbon alone is used to give high strength, then the carbon content of large sections is limited by the tendency of plain steels to crack when water-quenched.

Precautions on Adopting Alloy Steels

Alloy structural steels may be said to 'give their strength easily' in the sense that a given yield or ultimate stress value is accompanied generally by higher ductility and impact resistance. On the other hand, if their 'yield ratio' (i.e. yield stress/ultimate stress) is high, then a design based on this higher yield value has a lower plastic range available in case of unexpected overload. It is the long plastic range of good mild steel which makes it such a valuable structural material for everyday knock-about use at normal temperatures. Furthermore, many high tensile alloy steels are relatively notch-sensitive, and their fatigue resistance, when heat-treated to the higher values of ultimate stress, may not come up to expectations in service. This applies especially if the surfaces of the steel components become roughened and pitted, or if they are used in the black condition with patchy scaling and considerable decarburization. Fatigue test results obtained with highly polished specimens in laboratories should be applied with caution if the working part will be in use with a very different finish. It should also be realized that many alloy steel plates come from the rolling mill with surfaces which are inferior to those of carbon steels.

The designer will realize that although steels may be given increasing yield and ultimate stress values by heat treatment and by alloying, yet the elastic modulus of all steels is about the same. Reduction of section will, therefore, not always be justified if elastic effects are preponderant, for it is no use making a light-weight coach if the doors will not close when it is loaded with passengers. Special designs to secure stiffness will look after this aspect in most structures.

A word of caution must be given about the decreased weldability of many alloy steels. If they are introduced into service where mild steels have hitherto been in use, then great care must be taken to see that unauthorized welding — and especially for repair work — does not creep in. The replacement of a metal retaining-clip on an alloy steel connecting rod by a blob of weld metal once wrecked a diesel locomotive as a result of cracking from the brittle weld[3]. In the same way gas-cutting of alloy steels must be carefully supervised if operators have previously been accustomed to mild steel[4]. With a mention of the words ' hairline cracks ' and ' temper-brittleness ' enough has been said to caution engineers who may be changing over from the fabrication of mild steels to those containing considerable amounts of alloy elements.

Locomotives

Limitations of axle loads on track and on bridges have to be considered. Motive power is now provided by diesels, electric locomotives and gas turbines, and these machines contain plenty of special materials. The choice of the steel depends upon the ' ruling section ' of the structural component from the heat treatment point of view, and increase of section requires increased hardenability of the steel. An insight into the utilization of alloy steels for steam locomotives may be gathered from such published accounts[5] as that of the L.M.S. high-speed engine. The use of plate for the boiler shell and firebox containing 1·75-2·00 per cent nickel enabled a saving of weight of just over 2 tons with service design based on tensile strength. For a boiler weighing 28 tons on a locomotive scaling more than 100 tons this is not a large proportion, and in times like the present when nickel is in short supply it is wiser to use it for other purposes. A good quality higher manganese steel would suffice. The use of any alloys which might resist strainage embrittlement or caustic cracking in boiler plate, however, is a point to be borne in mind.

For locomotive frames the use of a steel with an ultimate stress of 35-40 tons/sq. in. instead of mild steel enabled 17 cwt. to be saved. The low-alloy material had a composition of : carbon 0·2, manganese 0·85-1·00 and chromium 0·45 per cent max., and this was chosen to restrict the hardening which may develop on the burnt edges when the frames are gas-cut to shape. Attention must be paid to the upper corners of the axle box spaces in the alloy steel frameplates as notch-sensitive conditions may eventually lead to fatigue cracks in service.

Motion Parts

As regards motion parts, the substitution of alloy for plain carbon steels enables reciprocating and revolving weights to be reduced, and a Ni-Cr-Mo steel of 50-60 tons/sq. in. ultimate stress saved 1000 lb. weight compared with a 40-45 ton Mn-Mo steel. As the surfaces of motion parts can be machined to, and maintained at, a good surface finish, one can expect to obtain fatigue resistance approximating to laboratory tests. At the same time stress raisers and notch effects must be watched in the design, and shops turning over to the machining of high-tensile steels may have to reduce machining speeds and feeds.

The connecting rods of internal combustion engines have to withstand shock effects when detonation occurs. Similarly coupling rods may be subjected to shock effects if there is slipping of driving wheels, and some engineers specify a minimum notch-bar value. This is readily obtained by using alloy steels, but also by employing special steels of the inherent fine grain size type[6]. Grain control is generally secured by careful additions of aluminium, but small amounts of vanadium also produce a similar effect. Results obtained from 4×4 in. sections after quenching in oil from 850°C. and tempering at 625°C. and air-cooling are given in Table 1.

Steel B was of the inherent fine grain type which most manufacturers can produce. Steel A was satisfactory, but care must be taken to avoid segregation effects in the ingots which might lead to pearlite banding in the forgings. Temperature control in heat treatment for this steel must be close, or fluctuations in Izod value may arise. It is possible that these may be associated with a transformation during heat treatment into the 'intermediate' region of the TTT diagram.

Drawgear

Couplings and drawbar hooks may be subject to shocks, and design should avoid severe stress concentrations and notch effects. Surface rubbing and deformation might produce the fine cracks known to exist in worn wrought-iron chains, but low-carbon steels with Mn contents just over 1 per cent and inherent fine grain size give high impact resistance and a low liability of strain age embrittlement.

Springs

The operation of laminated or coiled springs depends upon Young's modulus, and this is roughly constant for all steels. A high yield point to resist permanent set under load has, however, to be considered, and from considerations of suitable sections a quenched and tempered silico-manganese steel containing C, 0·5-0·6; Si, 1·8-2·0 and Mn, 0·7-1·0 per cent may be attractive. Plain carbon springs require to be water-quenched to give the desired yield point, and the incidence of quench-cracking may be high. The silico-manganese steel is not unduly expensive and can produce the right yield resistance by oil-quenching. This material, however, is generally more prone to scaling and decarburization during processing, and care should be taken that fatigue cracks do not start in service from these surface defects.

'Elastic Spikes' for holding down flat-bottom rails are frequently made of silico-manganese spring steel. Notch damage by corrosion has to be considered in these details.

Tires

Tires deteriorate by (a) wear of tread and flange, (b) shelling of the tread surface, (c) thermal cracking — 'heat cracking' — of the tread, (d) fatigue cracks from the bore surface, and (e) in rare cases, internal fatigue flaws from shatter cracks. Machining to a

TABLE 1 — STEELS FOR COUPLING RODS[6]

Ref.	C	Mn	Mo	Ult. stress, tons/sq. in.	Elong. % on 2 in.	Izod impact, ft.-lb.
A	0·25	1·56	0·30	41·5	27	93
B	0·37	0·98	—	42·6	30	91
Spec.	—	—	—	40 min.	20 min.	60 min.

very high surface finish will prevent fatigue cracks from the bore surface where it mates with the wheel centre.

British Specification 24 — Part 2 deals with four classes of tires, with ultimate tensile strengths ranging from 42 to 69 tons/sq. in. Only the sulphur and phosphorus contents are specified as regards chemical composition, and most tires are of plain carbon steel. Izod impact tests on pieces from standard positions generally give low results like 4 ft.-lb., and there is something to be said for trying to improve this value. The author[7] has previously pointed out that an initial crack in a rail or tire is less likely to be propagated in service in a steel of high notch-bar resistance, and consequently it may be observed during routine inspections and the tire removed before complete fracture. Incidentally for hardened rolls ' high carbon-chromium steels are universally used '[8].

To obtain better impact values and greater resistance to wear and thermal troubles, a Rotherham firm has for many years produced alloy steel tires. On the mountain lines in Canada these have given very satisfactory service with a yield point of 50 tons/sq. in. minimum and a composition of C, 0·70; Cr, 0·5 and Mo, 0·2 per cent. For an underground passenger electric railway, tires with a strength of 56-62 tons/sq. in. and composition of C, 0·40; Cr, 0·65; Mo, 0·45 and Mn, 1·45 per cent give an Izod impact value of 40 ft.-lb. min. These are cases where service experience suggests the limited use of an alloy steel in preference to plain carbon material.

In adopting alloy steels for tires one has to consider the possible applications of (a) flame-hardening of treads and/or flange corners to resist wear, and (b) repair of worn flange corners by welding. Alloy steels are more deep-hardening when subjected to these treatments, but the general effects are complicated.

There are some rather elusive principles which govern the surface crazing of tires, axle journals and rails, and they also probably govern the cracking of hard steels during surface grinding and the spalling of hardened steel rolls. Volume changes occur in steel during quenching and also during tempering, and the trouble about tires and rails is that the frictional heating cycles are uncontrolled and are repeated many times. A hard martensitic layer develops on the running surfaces of rails and tires, and from cracks which supervene fatigue flaws begin to grow. The latter curve round and may result in shelled patches, if not in transverse fractures.

These heat cracks depend upon (a) the composition of the steel, (b) its prior treatment (carbide particle size and internal stress), (c) thermal cycles and their frequency, and (d) segregation, surface seams and non-metallic inclusions. On the analogy of grinding cracks, one avoids high internal tensions, retained austenite, boundary carbide and steel-making defects. At first glance it might appear that alloy steels would fare badly, but this liability is offset by various factors which sometimes give net advantages[9]. Thus lower carbon may be used with alloy additions to provide the required yield point, and this means reduced cracking on chilling. An alloy steel may chill with less acute volume changes and, therefore, may have a lower internal stress. Concentrated martensite cannot form unless carbides go completely into solution, so to this extent relatively large carbide particles are desirable with a low solution rate. Chromium will reduce the speed of diffusion and solution, and austempering and martempering effects may take place more readily than in carbon steels. It has been shown[10] in connexion with the phenomenon of ' delayed cracking ' in steels of about 450 Brinell that some alloy compositions are better than others.

Rails

Rails are required to be hard-wearing and to have a low liability to breakages. The normal production practices of British rail-makers have been very successful in avoiding hairline or shatter cracks in rails, and wear is perhaps the greatest consideration.

As a result of recent publications we now know a great deal about the optimum rail steels for resisting wear. Losses must be considered from the point of view of (a) side-cutting of the head of the rail on curves, (b) normal wear on straight track, and (c) corrosion-wear effects due to the working atmosphere.

Results for (a) based on measurements during 25 years on the sharp curves of the *electrified* St. Gothard line in Switzerland have been selected[11] and included in Table 2.

The chromium rail with a structure of tempered martensite has given the best wear result, but such rails are expensive. Otherwise a eutectoid rail containing not more than 1·5 per cent manganese appears to be the best investment, and this is the type now used on German main lines.

The author once initiated a study of the wear of straight track in Britain and the results now show[12] that corrosion effects play a great part. Various contents of C, Mn and Cr were included in the trials, and if one divides each of the last two elements by a factor of 3 or 4, and adds the result to the carbon content, a 'carbon equivalent' is obtained. In the range examined Dearden found that 10 per cent reduction of wear follows for each 0·1 per cent of equivalent carbon. Austenitic 12 per cent manganese steel is well known to give excellent service for busy crossings, and 0·5-1·0 per cent Cr is also said[13] to show improved life in these positions. A trial by the author of Cr-Ni austenitic inserts (245 Brinell) welded from Armex 2 electrodes into the running surfaces of ordinary rails gave remarkable wear resistance, but this is not an economic solution at present. The development of continuous casting machines for rails may solve the problem in the future.

Copper-bearing steels corrode less in the open air than plain steels, but this effect was not obtained in steam-traffic tunnels. No low-priced rail steel compositions are known which will effectively combat the corrosion factor.

Carriages and Wagons

Low-alloy steels having tensile strengths of 33-40 tons/sq. in. are of great interest in connexion with rolling stock. Sections and weight can be reduced as compared with mild steel, but this advantage would only be worth-while if increased corrosion resistance were also obtained. Additions of 0·6 per cent Cr and 0·5 per cent Cu to material with 0·15-0·20 per cent carbon give satisfactory results, and experiments on floor plates for coal wagons show a saving of weight of 20 per cent for equal service life. In passenger coaches and kitchen cars the 18/8 austenitic steel finds

TABLE 2—RAIL ON THE ST. GOTHARD

REF.	WEAR INDEX	BRINELL HARDNESS	C	Mn	Cr	Cu	CONDITION
NMCR	0·138	410	0·31	0·82	1·04	—	Heat-treated
KR	0·158	260	0·60	1·55	—	0·19	As-rolled
VT	0·291	270	0·73	0·74	—	0·21	As-rolled
KO	0·296	330	0·80	0·70	0·77	0·40	Compound rail
Normal	1·960	210	—	—	—	—	As-rolled

useful employment, and this must be of welding quality if welding is to be used in fabrication. The production of bogies of welded low-alloy steels was at one time popular, but the incidence of fatigue cracks near the welds must be avoided by very careful design in these intricate assemblies.

Specifications

Since a large railway organization uses considerable tonnages of steels, there is sometimes a tendency to introduce special specifications for material. This should be avoided as much as possible, as it leads to complications in the steel-making plants. Furthermore additional and intricate mechanical tests should be given deep consideration before they are introduced into specifications. The deleterious effect on costs and productivity of ill-considered specifications has recently been indicated[14], and the effect could be considerable if one is embarking upon a new programme for utilizing alloy steels.

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