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High-strength cold-rolled steels

by B. J. PARRY*

SYNOPSIS

Three types of high-strength cold-rolled steels are discussed. Two are currently being developed at Iscor: rephosphorized steel and niobium microalloyed steel. Heat treatment after cold rolling is carried out in batch annealing furnaces. A third type, dual-phase steel, which requires a continuous annealing treatment for economic production, is also described.

The properties, strengthening mechanisms, and applications of these three steels are examined.

SAMEVATTING

Drie soorte koudgewalste staal met 'n hoë treksterkte word bespreek. Twee daarvan word op die oomblik by Yskor ontwikkel: geherfosforiseerde staal en mikrogelegeerde niobuimstaal. Die hittebehandeling na die koudwasling word in lotuitgloeioonde uitgevoer. 'n Derde soort, dubbelfasestaal, wat 'n ononderbroke uitgloeibehandeling vir ekonomiese produksie vereis, word ook beskryf.

Die eienskappe, versterkingsmeganismes en aanwendings van hierdie drie soorte staal word ondersoek.

Introduction

The development of high-strength formable steels began many years ago, but the most rapid advances in this field have taken place during the past ten years or so. The main contributory factor to the surge of interest in this subject was the massive increase in fuel prices in the early 1970s, which encouraged the manufacturers of motor vehicles to look at all possible methods of reducing fuel consumption.

One way of achieving this was the reduction of the mass of a vehicle by the use of thinner materials. From a safety point of view, however, this could not be done without an increase in the strength of the material. Therefore, new steels had to be developed to take the place of the conventional mild steels traditionally used in the manufacture of automobiles.

The initial work was concentrated mainly on chassis parts, for which hot-rolled thicknesses were mostly supplied. More recent work, however, has been directed towards a reduction of the thickness of body panels, which are produced from cold-rolled steels.

Hot-rolled wide strip can be processed only down to approximately 1,6 mm thick. The correct control of mill temperatures, necessary to give satisfactory structures and good mechanical properties, is difficult to achieve below 2 mm. For this reason, body panels and structural members of a thickness less than 2 mm are produced preferably from cold-rolled steels.

In addition to the need for a reduction in body mass, other factors have contributed to the drive for stronger materials. Increasingly stringent safety specifications with respect to deformation resistance are being introduced, and motor manufacturers are looking more and more towards improved dent resistance in body panels[1,2].

Iscor, in conjunction with the motor industry, recently embarked on a programme to develop a series of high-strength cold-rolled (HSCR) steels to meet the growing demand for these products. This paper outlines the choice of materials made, the properties obtained, the processing methods and parameters used, and the applications in the motor industry.

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Classes of HSCR Steels

For the purpose of this paper, HSCR steels are classified into three basic types. It must be emphasized that this classification is based mainly on Iscor's present approach to this subject.

Rephosphorized Steel

This is, basically, a low-carbon, aluminium-killed (AK) steel in which the phosphorus content is adjusted during the steelmaking process to between 0,06 and 0,10 per cent. The phosphorus content of normal AK deep-drawing steels is usually less than 0,02 per cent.

Phosphorus strengthens the ferrite lattice by forming a substitutional solid solution[1,3]. The yield and tensile strengths are increased by approximately 20 to 30 per cent above those of conventional deep-drawing steels, while the elongation is reduced by about 10 to 15 per cent. The composition and mechanical properties are summarized in Table I. A typical example of a low-carbon AK steel (e.g. BS1449 KCR1, SAE 1006, DIN 1623 ST 14, JISG 3141 SPCE) is shown for comparison.

The formability of this type of steel is good when compared with low-strength AK steels. Fig. 1 shows the formability limits of the first batch of rephosphorized material processed at Iscor to cold-rolled sheet 1,0 mm thick. The yield strength of this batch varied between 245 and 255 MPa. A curve for Iscor's conventional AK steel, produced to BS 1449 KCR1 specification, is shown for comparison. The yield strength of this particular grade varies between approximately 180 and 200 MPa. It can be seen that the formability of the rephosphorized steel compares favourably with that of the AK steel and is only slightly lower.

Basically, rephosphorized steel is useful in the yield strength range 240 to 275 MPa and for applications where good formability is required.

High-strength Low-alloy Steels

Where greater strength is required, generally above

TABLE I

COMPOSITION AND MECHANICAL PROPERTIES OF REPHOSPHORIZED AND AK DEEP-DRAWING STEELS

Type	Typical composition, %					Typical mechanical properties		
	C	Mn	Al	Si	P	Yield MPa	Tensile MPa	Elongation %
Rephosphorized Supraform CR 235	0,06	0,30	0,05	0,04	0,08	245	380	36
AK EDD (BS1449 KCR1)	0,06	0,25	0,05	0,02	0,015	180	300	42

300 MPa yield, other strengthening mechanisms need to be employed to supplement solid-solution hardening.

Microalloying with elements such as niobium, vanadium, and titanium can produce fully batch-annealed cold-rolled steels with yield strengths between 300 and 400 MPa and with elongations in excess of 28 per cent.

Iscor is currently developing two steel grades in this category, with a minimum yield strength of 300 and 340 MPa respectively. Manganese and silicon are added for solid-solution strengthening, while niobium is added in small quantities for precipitation strengthening and grain refinement. In fact, precipitation strengthening is more important in this type of steel in the hot-rolled condition than in the cold-rolled form[4]. The control of hot-rolling temperatures results in a fine precipitation of niobium carbides, nitrides, and carbo-nitrides, which has two effects:

(a) grain growth is inhibited, producing a fine, equiaxed ferrite structure, which increases the toughness and tensile parameters;
(b) yield strength is increased by precipitation hardening.

After cold rolling and annealing, the fine grain size is retained, although it is slightly coarser than in the hot-rolled coil. However, much of the precipitation-hardening effect is lost during annealing owing to coalescence of the fine precipitates formed during hot rolling. This is the main reason that cold-rolled steels of this type have a yield strength of 80 to 150 MPa lower than hot-rolled steels of the same composition.

Typical composition and mechanical properties of the material produced at Iscor to date are shown in Table II.

Fig. 2 shows the formability limits for 1,6 mm Supraform CR300, with a yield strength of 340 MPa. The curve for BS1449 KCR1 material of the same thickness is included for comparison.

Dual-phase Steels

The above two types of HSCR steel, i.e. rephosphorized and HSLA steels, can be processed with Iscor's existing cold-mills equipment, which is limited to a batch heat-treatment process.

In the past ten years, Japanese steel companies have made tremendous strides in the field of continuous annealing of cold products[5]. The modern continuous-annealing lines developed in Japan are capable of producing a range of materials with yield strengths varying from 200 to 1000 MPa.

One of the more interesting of the products produced on these lines is a dual-phase steel[2], which consists of a dispersion of martensite in a ferrite matrix. This is achieved by the heating of the strip to an intercritical temperature of between 800 and 850 °C, and rapid cooling.

The unique property of these steels, which makes them extremely useful for the manufacture of autobodies, is that they possess bake hardenability without being susceptible to strain ageing. This can be explained as follows.

The ferrite lattice becomes supersaturated with carbon and nitrogen during the rapid cooling process. During the low-temperature baking that follows painting by the automobile manufacturer, fine carbides and nitrides precipitate, thereby increasing the strength of the body panel *after* it has been formed and assembled. The yield strength of a typical dual-phase steel can be increased by as much as 50 to 100 MPa during baking.

Single-phase steels produced with excess solute elements in the ferrite lattice would be susceptible to strain ageing, which would cause the appearance of unsightly stretcher strains after pressing. In dual-phase

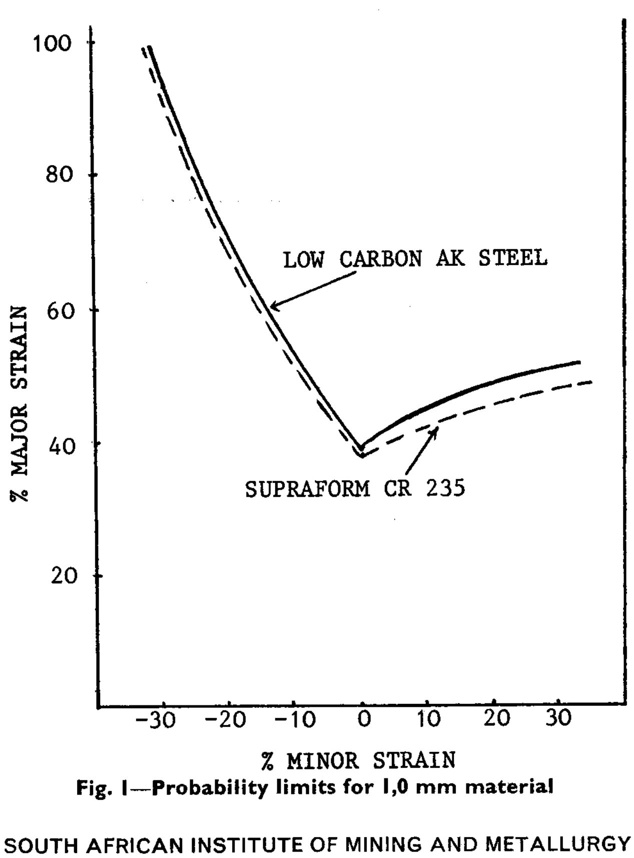

Fig. 1—Probability limits for 1,0 mm material

TABLE II

COMPOSITION AND MECHANICAL PROPERTIES OF HSLA STEELS

Type	Typical composition, %					Typical mechanical properties		
	C	Mn	Si	S	Nb	Yield MPa	Tensile MPa	Elongation %
Supraform CR 300	,07	0,90	0,20	,005	,02	330	450	30
Supraform CR 340	,09	1,00	0,25	,005	,03	375	480	28

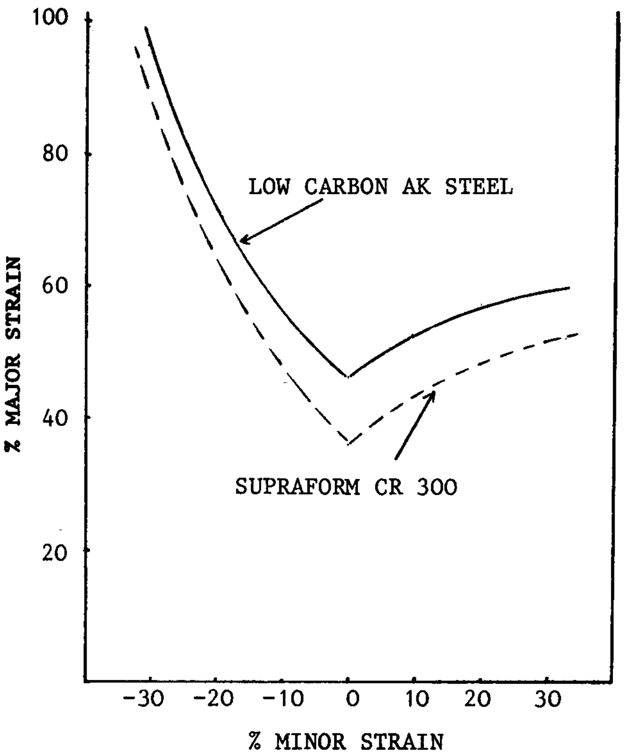

Fig. 2—Probability limits for 1,6 mm material

steels, however, the mismatched region between the martensite and ferrite phases is a ready source of mobile dislocations, which produce smooth yielding characteristics during the pressing operation.

Processing Route

Fig. 3 is a schematic diagram of the production flow for cold-rolled products.

After hot rolling, the strip is coated with a film of oxide, which must be removed before further processing. This is performed in a pickle line using hydrochloric acid, and the clean strip is thoroughly rinsed, dried, and oiled to protect the surface from corrosion before the next process.

The pickled coils are cold reduced in a tandem mill of four or five consecutive 4-high stands to the final thickness required by the customer. The percentage reduction carried out is reasonably important and can influence the properties of the finished product. For deep-drawing AK steels, the optimum reduction is 60 to 70 per cent, and this can also be achieved with the rephosphorized material without the use of excessive roll forces. However, it is difficult to apply such large reductions to

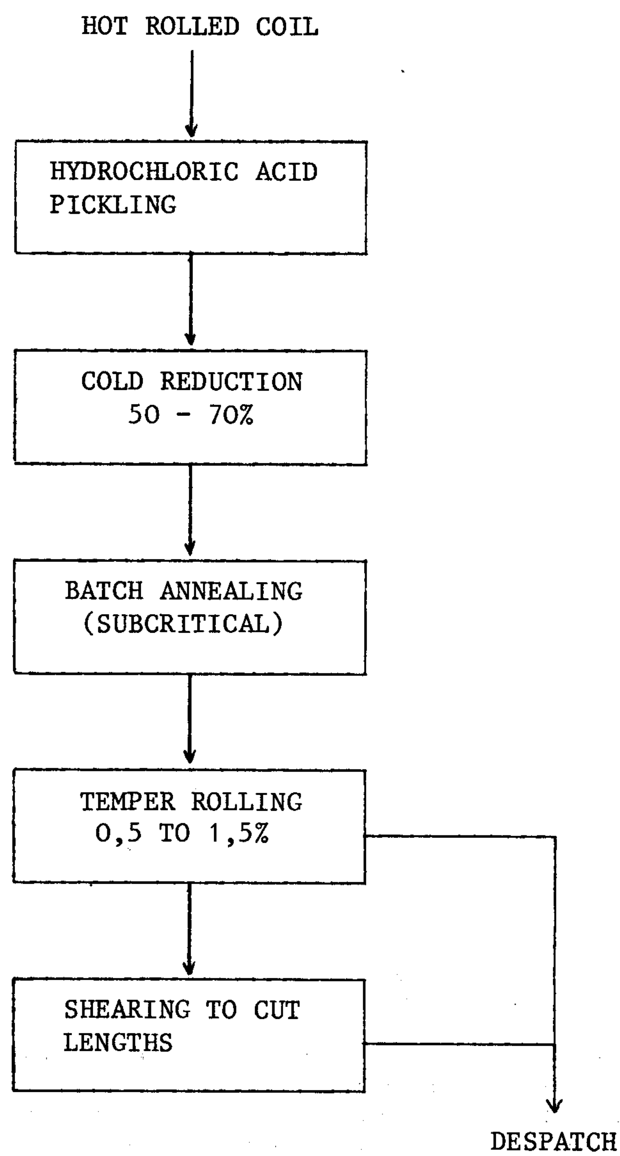

Fig. 3—Production flow for cold-rolled products

HSLA steels because of their high work-hardening characteristics. Reductions of about 50 to 55 per cent are employed with these steels.

After cold reduction, the material is batch annealed in single-stack bell furnaces at sub-critical temperatures, of approximately 650 °C. The main purpose of this heat treatment is to recrystallize the severely cold-worked structure formed during rolling, and to restore the desired mechanical properties and formability to the material.

Each furnace contains three tightly-wound coils with a total mass of approximately 60 t, so that, in order to fully anneal the central portions of these coils, long heating times must be employed, usually up to 60 hours.

In the HSLA steels, the fine precipitates formed during hot rolling coalesce into coarser particles, and part of the precipitation strengthening mechanism is therefore lost. The solid-solution strengthening mechanism is not lost, however, and careful control of the annealing parameters ensures that the fine-grained characteristics are retained.

The final processing unit in the cold mills is the temper mill, where a light-skin pass of approximately 1 per cent is applied to the material to remove yield-point elongation, apply the desired surface texture, and impart good shape.

If required, the coils can be cut to sheets before they are despatched to the customer.

Applications in the Motor Industry

The use of cold-rolled high-strength steels in the South African motor industry is decidedly in its infancy, and many companies are adopting a wait-and-see attitude. This is very understandable, since the change from conventional steels to stronger steels of different thicknesses will mean expensive modifications to press tooling. However, some companies have begun production trials. The areas in which the various types of steel are being applied are illustrated in Fig. 4.

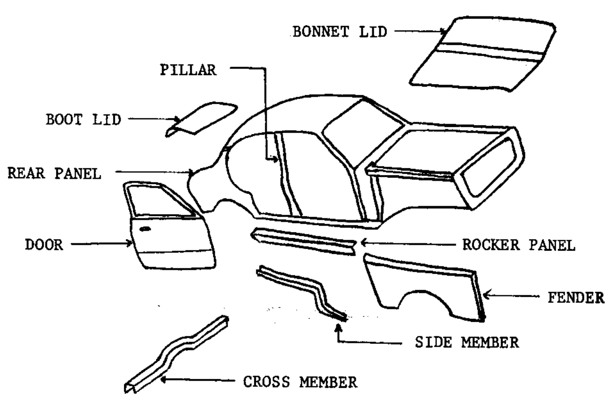

Fig. 4—Autobody parts from HSCR steels

Rephosphorized steel is mainly being used for inner and outer body panels, and for lighter structural parts up to 1,2 mm thick. Reductions in thickness of approximately 15 per cent are being achieved over conventional AK material. The higher yield stress of rephosphorized steel improves the dent resistance of exposed body panels such as doors, fenders, etc. The outer panels of bonnet and boot lids are much stiffer and require less bracing on the inside. The good formability of rephosphorized steel also makes it suitable for some unexposed panels that require a deep draw.

HSLA steels are used for main structural components generally in thicknesses above 1,2 mm, where a degree of formability is required, e.g. chassis cross members and side members.

Dual-phase steels are suitable for exposed body panels because of their non-ageing characteristics and because they exhibit bake hardenability. These steels are increasing in popularity in Japan, since most major steel companies possess the continuous-annealing equipment necessary to produce them. The capital outlay for such equipment is extremely high; a line capable of producing 40 000 t per month costs more than a hundred million rands. Many large steel companies in the West, including Iscor, are agonizing over whether to invest so much capital, especially in the present economic climate.

General Considerations

Potential users of HSCR steels should remember a few general factors when considering these steels as replacements for conventional mild steels.

The welding characteristics differ somewhat, and experience has shown that modifications have to be made to the current and time settings of resistance welding equipment, particularly in the case of HSLA steels.

Minor modifications to die design are often necessary, e.g. larger and smoother radii in complex pressings. Major, expensive changes are sometimes required when thinner materials are used, and this is one factor that is inhibiting the development of these steels. However, it is expected that, as new models are introduced that require new tooling, the pace of development will increase, and that HSCR steels will play a major role in the future construction of automobiles.

Conclusion

Of the three types of high-strength cold-rolled steels discussed, two are being developed by Iscor since their manufacture is possible with existing plant. A third type, dual-phase steel, cannot be processed without sophisticated continuous-annealing equipment, which requires a large outlay of capital.

With the need to meet increasingly stringent safety standards and to lighten motor vehicles in order to reduce fuel consumption, the development of HSCR steels will remain high on the list of priorities of most major steel producers in the years to come.

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