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From Niche to Commodity, 3CR12—a Ten-year Scenario

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This paper refers to steels that have evolved from ferritic stainless steels and have been variously designated as 'weldable ferritics' and 'utility ferritics'.

As these 'new age' steels now bear such slight resemblance to the ferritics, we have chosen to refer to them as lean-alloy dual-phase (LADP) steels to distinguish them from their progenitors.

Signposts

Long the Cinderella of the stainless-steel family, lean-alloy utility ferritic stainless steels have rapidly come of age in the past ten years. While the ferritic steels have generally been caught in the evolutionary trap of their metallurgical and marketing limitations, the new utility chromium steels have been engineered for the general-purpose and structural markets.

The signposts to this structural opportunity were visible when the first Sealand Containers were framed in the now historical Crucible E-4 over twenty years ago. But a far more significant signpost has been the outstanding performance of a broad spectrum of sophisticated static and dynamic loaded structures that now lead the state of the art in transportation.

This development has been catalysed by the invention and development of better steels at better prices using better design technology available from new CAD software and ASCE design codes.

The awareness of a need for more-stable long-life materials has been emphasized by the automotive industry. It has switched to sophisticated galvanized and protection systems with life warranties in response to consumer logic and the demand for overall cost-effectiveness in use. It is no longer acceptable to write off a car body in marine or salty road conditions over the relatively short lifetimes experienced up to the mid 1980's.

Better Steels

MS&A's work on lean-alloy stainless metallurgy (described in J. Hewitt's paper 'High-chromium controlled-hardenability' at this Conference) has produced the means for optimal alloy permutations and combinations for improved properties and simplified process routes. This, in turn, has permitted optimal *cost* alloying. The result has been a selection of mechanical properties, improved weldability, and superior corrosion resistance without stress–corrosion cracking.

This extension of metallurgical understanding beyond the Kaltenhauser formula has also extended the family of lean-alloy dual-stabilized/dual-phase (LADP) utility stainless steels up to and including 18 per cent chromium steel with the superior mechanical welding characteristics of the current state-of-the-art 3CR12.

Better Prices

The theoretical possibility of producing a 12 per cent chromium stainless steel at the base carbon-steel price plus the cost of the alloying elements is a clearly attainable scenario, and in time should lead to a cost premium of less than 400 US dollars per tonne over the carbon-steel base. The processes and process routes for this to happen are proven, and simplified production loops have already demonstrated a halving of direct production costs.

New Age Materials

Many of the new age materials deal with the everyday catastrophic phenomenon of rust and rust-aided abrasion, which costs the world 4 per cent of its gross earnings (the equivalent of an annual OPEC crisis).

The paint, galvanizing, and coating industries have done a useful job in helping to treat the symptoms, but the steel industry has been slow to address the cause. And so, the appalling cost of rust in terms of wasted man hours, productivity, energy, and even lives, continues. Steel's vulnerability is the market opportunity of the 'new age materials' (plastics, ceramics, and composites), which now focus on the low, high, and middle ground of the 'corrosion' market. The steel industry has remained linked to the rust cycle for its demand momentum and its scrap supplies, and on the coating industries for performance enhancement.

The emergence and recognition of the new age (LADP) steels in Europe is therefore an important event in steel's evolutionary history, and affirms their role as technically advanced new age materials. (The Technical Editor of the English *Sunday Times* refers to 3CR12 as the 'steel overhauled to fight plastics'.)

Today, the forerunner of this generation, 3CR12, is the

TABLE I
SOME NOMINAL COMPOSITIONS OF THE NEW 12 PER CENT CHROMIUM STEELS

Type	Structure	C	Cr	Ni	Ti	Other
409	Ferritic	0,025	11,0	–	0,5	
408	Ferritic	0,025	12,0	–	0,4 0,7	Nb 1,0 Al
AM-363	Martensitic	0,04	11,5	4,0	0,5	
E-4	Martensitic	0,05	11,25	0,9	–	
3CR12	Dual phase	0,025	11,50	0,6	0,3	1,25 Mn.N
1,4003	Martensitic	0,020	11,0	0,5	–	1,00 Mn.N

TABLE II
MECHANICAL PROPERTIES IN COMPARISON WITH AUTOMOTIVE STEELS

Type	Yield strength, MPa	Ultimate tensile strength, MPa	Elong. %	DBTT
409	234	448	32	R.T. +
408	358	517	27	R.T.
AM-36 3	724	848	12	–45 C
E-4	276	483	29	–50 C
3CR12	355	560	29	–30 C
1,4003	320	500	25	–50 C
Al (5xxx) 1/2 HARD	200	300	18	None
304	260	560	40	–200 C
CR1	104 (min)	280 (min)	38 min	+ 10–25 C
D-P	345	415	25	–18/50 C

The development of dual-phase and acicular HSLA steels has allowed property optimization by constitutional alloying and controlled rolling to obtain improved yield strength in the as-rolled condition

These principles are metallurgically viable for the 11/12% Cr steels, and considerable work has been done on the determination of the optimum alloy content to achieve stainless steels with controlled transformation/hardenability, thus avoiding expensive heat treatments

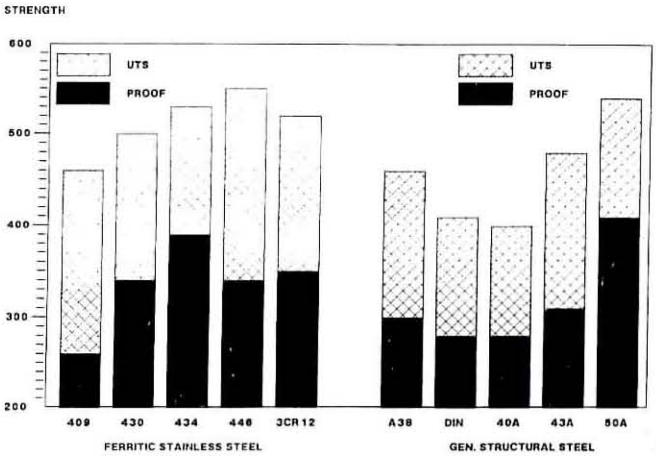

FIGURE 1. Strength and weldability of stainless ferritic steels compared with those of structural steels

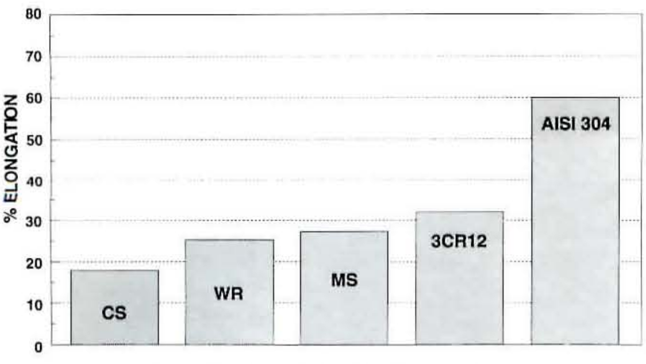

FIGURE 2. Ductility of various steels

material of choice in the major coal, sugar, power, transportation, and petrochemical industries, while new related steels are expanding the usage horizon still further.

The New Generation

The new generation of LADP steels (Table I) have improved weldability and properties in thick and thin sections with higher proof strengths than the austenitic steels, are potentially half the cost (at current nickel prices), and are extremely easy to form, weld, and fabricate. Their mechanical properties match those of the generally used structural steels as shown in Figures 1 and 2 and Table II.

While the mechanical properties of LADP steels compare well with those of carbon steel, their key design feature is a corrosion resistance over 200 times better. This means that the designer can omit the corrosion allowances built into heavy chassis, beams, and load-bearing elements. He can also design differently, and introduce integral space frames or monocoque structures that are lighter, stronger, and safer, and that will outlast carbon-steel products many times over.

Corrosion resistance has finally become a key parameter in a new generation of structural-steel design.

Production Technology

The new production technology is elegantly simple and applicable to both stainless-steel and mild-steel facilities. The process of carbon steelmaking and stainless-steel making are essentially the same. Both are melted, cast, rolled, annealed, and pickled. Melting, annealing, and pickling technology may vary but, for a typical 12 per cent LADP stainless steel, it is theoretically and practically viable to follow the same flowchart and use the same equipment with the simple addition of argon or vacuum refining (Figure 3).

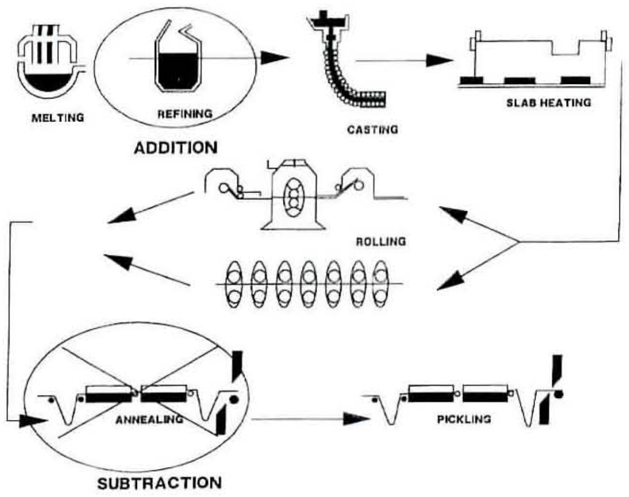

FIGURE 3. Hot-strip flowchart, showing the modifications required for the production of 3CR12

This means that the full economy of scale of a modern carbon-steel mill can be applied to the mass production of these steels.

An innovation by the producers of 3CR12 now eliminates the costly step of annealing after hot-rolling, offering major benefits to hot mills with limited or no annealing facilities. The common problem of slab cracking during the cooling of ferritic stainless steel has also been eliminated, together with the costly need to hot-grind (at 200 to 300 °C) and hot-charge slabs prior to rolling. The slabs are stable, can be stored or 'banked', and can be cold-ground.

Pickling procedures have been developed to enable pickling in all the standard pickling acids used for stainless or mild steels. Most 3CR12 plate at present is pickled in hydrochloric acid.

With the current growth in demand for these efficient, low-cost utility stainless steels, the convergence of cost with those of coated steels and fabricated components will have a profound effect on demand, with a natural trend towards production in higher-volume, low-overhead mills.

History and Evolution

It is a matter of historical fact that the unique structural properties of all stainless steels have been sadly neglected owing to an almost complete absence of encoded useful information for structural engineers. This appalling state of affairs was at last partially remedied when the properties of cold-formed sections were codified for general use by the AISI and ASCE in 1991.

For the first time, structural engineers are able to use internationally acceptable design references, and for the first time stainless steels are officially recognized as structural steels. (Much more sponsored work still needs to be done to include hot sections, to broaden the usability of limit-state design technology, and to promote the use of the codes themselves.) However, there have been entrepreneurial milestones on the road to structural viability in which individual companies have effectively used the unique structural qualities of stainless steels.

The outstanding performance of the precipitation-hardened grades in highly stressed aircraft landing gear is already archival. So is rigidized stainless sheet, the Budd rail car, the Sinowski Dome, the thin-skin Clover Leaf wine tank, the GM bus, the Sealand intermodel container design, and the stainless rebar reinforcement of Alpine tunnels.

For 75 years, chromium ferritic stainless steels have shared with the martensitic stainless steels the generic defect of poor weldability. As a result, they were used for specialized thin-gauge applications in which they soon dominated the market. This dominance by ferritic stainless steel of the industries producing automotive exhausts, domestic kitchen sinks, utensils, trim, and appliances needs no review; nor does the dominance by martensitic stainless steels of the markets for razor blades, surgical instruments, cutlery, cutting tools, and specialized high-temperature products.

Ironically, the weldability problem with chromium steel that plagued Brearley in 1913 was to remain for 65 years, a sad case of metallurgical neglect.

The generic defect of single-phase grain growth and embrittlement was partially solved by the 409 container grades of the 1970's, but was finally overcome by the work on 3CR12 over the past ten years. Today, via know-how arrangements, technical agreements, and independent research, European mills have added their technology to the dual-phase database, while in South Africa new research has achieved major breakthroughs in process economics and weldability.

Meanwhile the 220 000 kt of 3CR12 operating cost-effectively in widely diverse industries in Europe, Africa, and Australia is a market test that demonstrates its massive potential worldwide.

Design Revolution

Design confidence in the user-friendliness and good mechanical properties of 3CR12 has grown, catalysed by the design of more efficient structures. The excellent corrosion resistance has eliminated the need for corrosion allowances, and has seen the introduction of ultra-long life, high pay-load monocoque, and integrally safe vehicles.

The intelligent use of sophisticated software programs has also created a new role for LADP stainless steel as a competitive and optimal material of construction. The application of new CAD software to stainless-steel design has reduced construction costs, improved payloads, increased operational lives, and greatly improved user safety. As a result of these new standards of performance, major international specifiers are selecting low-alloy stainless steel for a variety of static and dynamically loaded structures ranging from electrification masts to road vehicles and railway rolling stock (Figures 4 and 5).

New Stainless-steel Designs of Vehicles

An important design breakthrough for modified 12 per cent chromium steels was the use of the E4 variant in the General Motors Rapid Transit City Bus. This was an integral monocoque shell in AISI 409 stainless steel, spot welded to E-4 'carline' portal frames. The buses entered service in 1977 and have been produced at rates of up to 1000 per year to the current time. Minimum service lives of 15 to 20 years are now well established, with the fleet now recording over 1,5 million miles per day!

The British development programme for 3CR12 vehicles was designed to further optimize performance, safety, and efficiency with lighter, high-tech space-frame structures. This was achieved with the surprising bonus of first cost savings, which make the designs immediately competitive with their carbon-steel and aluminium counterparts.

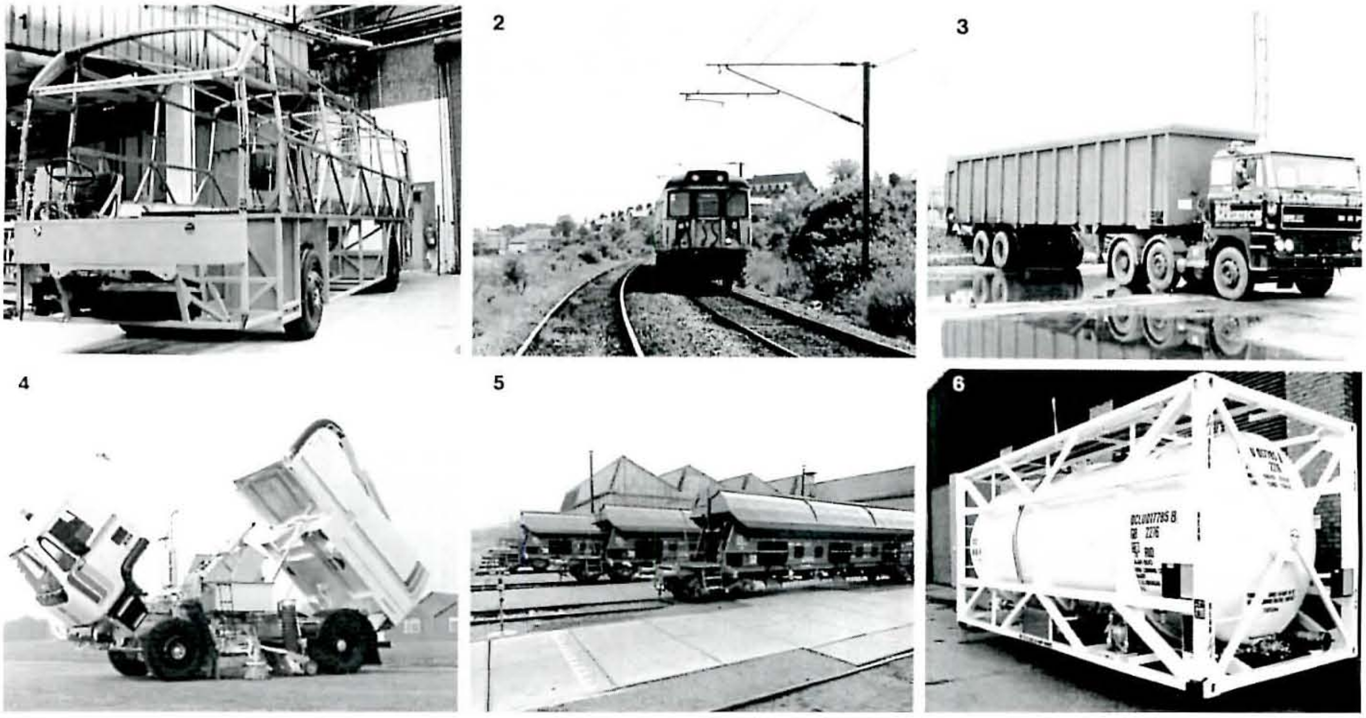

FIGURE 4. Some uses of LADP stainless steel
(1) 3CR12 integral '425' safety frame (UK), (2) 3CR12 British Rail electrification support (UK), (3) 3CR12 bulk conveyor (UK), (4) 3CR12 road sweeper (UK), (5) 3CR12 fertilizer rail hoppers (Belgium), (6) 3CR12 tank-trainer frame (UK)

FIGURE 5. Electrification masts of LADP stainless steel

In the case of the Integral 425 coach (Figure 6), the immediate benefits were
- about twice the rollover strength of conventional vehicles
- better fuel economy, saving the full cost of the vehicle in its first ten years of operation (Figure 7)

FIGURE 6. The 3CR12 Anglo-French Integral 425 luxury 51-seater touring coach, which has set new standards of safety, economy, and comfort in Europe

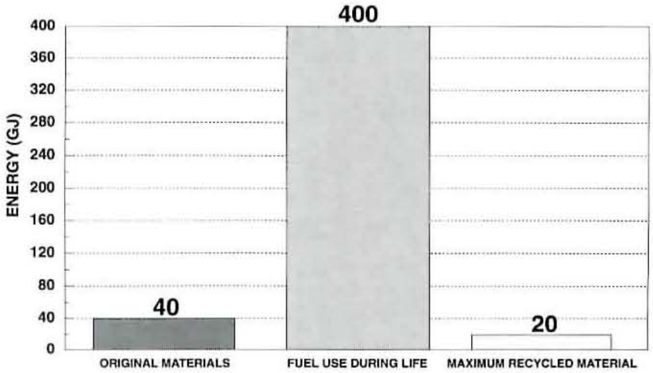

FIGURE 7. Energy consumption

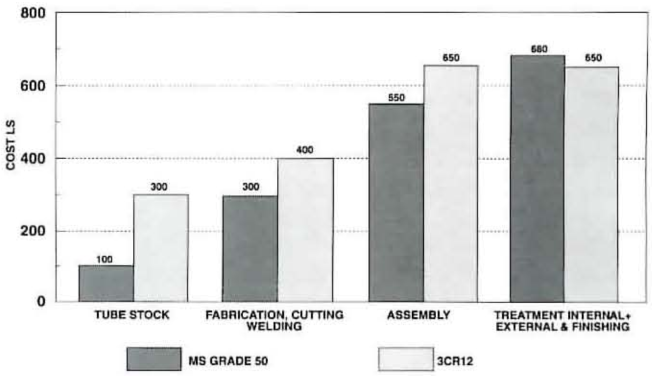

FIGURE 8. Manufacturing costs of large, light tubular space frames ($16\ m^3$, 220 kg)

- increased payload (up to 5 extra passengers)
- a marginally lower cost of production resulting from savings in material mass, including 300 kg of twin-pack epoxy protective coating and wax filling of tubular members (Figure 8).

Similar benefits accrue to the front-line Peugeot ambulance and the Ava sports car, where the lighter, more rigid bodies also greatly improve acceleration and roadholding (Figure 9).

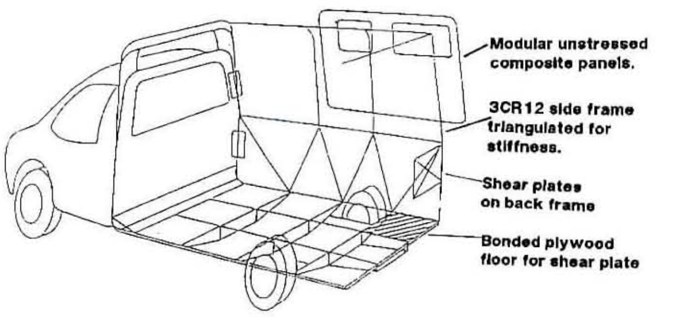

FIGURE 9. Rigid stainless-steel ambulance spaceframe permits independent suspension for better handling

The LADP's have also enabled significant advances to be made in the design of rail-freighters and coal hoppers in South Africa and Queensland (Australia), with tare reductions of up to 50 per cent and payload increases of 45 per cent (Figures 10 and 11).

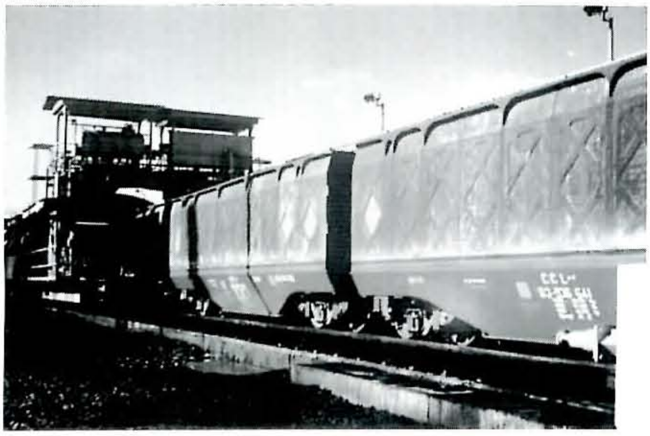

FIGURE 10. 3CR12 Jumbo CCL coal wagons being unloaded at Richards Bay, Natal

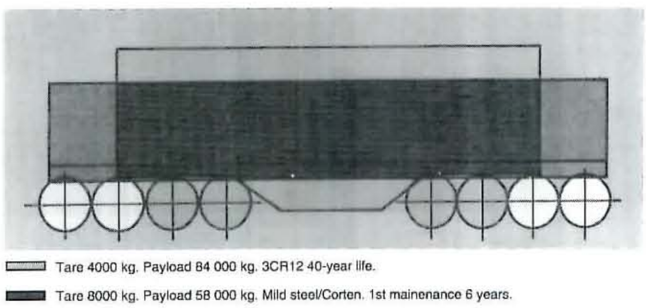

FIGURE 11. An example of 3CR12 in rail transport design. A monocoque approach for high-capacity coal wagons has allowed a 45 per cent increase in payload and a 50 per cent reduction in weight, in addition to significant life improvements

The coach, bus, and ambulance designs substituted lightweight, rigid tubular space frames for the conventional body-on-chassis designs. The tubular elements were selected by a CAD system ('WEST'—Weight Effective Structural Tubing), which optimizes tubular structural elements and utilizes the work-hardening characteristic of stainless steel in the retangular-section product. Body shape and functional features were then developed by the design team, followed by finite element analysis for structural refinement and optimization. Finally, crash/rollover simulation to show the rollover deflections was carried out on the Cranfield Crash D programme to comply with ECE Regulation 66 (Figure 12).

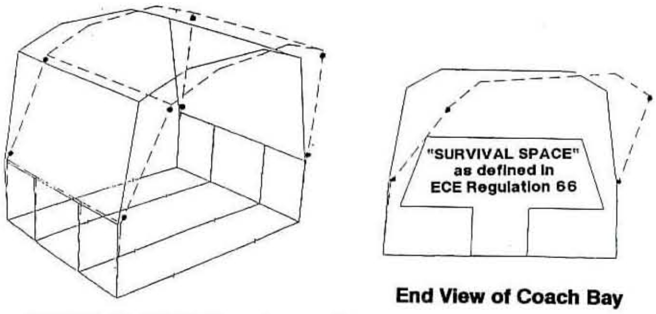

FIGURE 12. CRASHD result, stage D—structure enters survival space deflection of loaded points = 360 mm

In the case of the sports cars, a monocoque 'integral complex beam' body was designed. Here, again, the lightness, rigidity, and robustness of the structural shell is demonstrated by 26 top three placings in 76 British hill-climbing competitions (Figure 13). To date, the outstanding perfor-

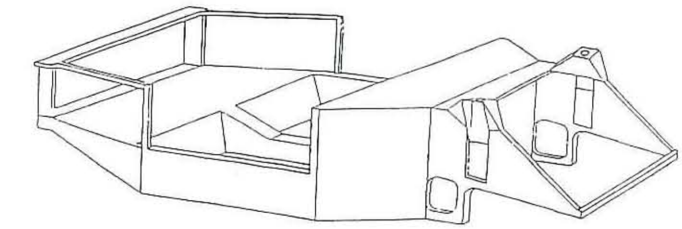

FIGURE 13. 3CR12 car monocoque, 15 per cent of unladen weight

mance features of the large commercial-production vehicles have been demonstrated over 10 million vehicle miles of service operation. There are now 100 buses in service with the London Bus Company, and another 100 coaches in service throughout Europe with a variety of coach operators, including the Gatwick–Heathrow Speedlink.

The Ava sports car is produced for a limited enthusiast market, and has already set new styling trends, including some flattering likenesses from Lotus and Mazda.

Economics

The key to the low-cost stainless-steel body frame is that the stainless-steel core structure contributes only 15 to 20 per cent to the overall vehicle's mass and less than 2 per cent to the vehicle's sales value. With monocoque or integral space-frame construction, the design is therefore relatively insensitive to material cost. However, the structural strength, ease of assembly and welding, and corrosion resistance of low-alloy stainless steel, enable design optimization to offer a *first cost* saving over the conventional standard materials of construction (including coated carbon steels and aluminium).

The advanced composites, including carbon-fibre reinforced plastics (CFRP), while structurally attractive, have not yet demonstrated commercial viability, the costs still being regarded as prohibitive, although viable for satellite and Formula I designs. Their current energy cost of 100 times their own weight in oil remains a major obstacle for volume production.

The advent of computer-aided design and innovative, computer-literate designers has opened a new window of opportunity for stainless-steel structures. The demonstration of first cost savings, in addition to major lifecycle and safety advantages over competitive materials, promises to change the map of stainless-steel specification.

The past instability of nickel supply and pricing has raised the vulnerability of the stainless-steel industry and the role of nickel as a potential limitation to growth.

The molybdenum shortages of the 1970's resulted in permanent substitution of the molybdenum grades. Similarly, the nickel fluctuations of 1988 and the new resulting price plateaus will result in more substitution by alternative materials. And if these needs are not met by the stainless-steel industry, they will be met by alternative materials.

It is perhaps of some comfort that 40 per cent of the cold-rolled nickel stainless-steel market's needs can be met by the cold-rolled ferritic and low-alloy stainless steels, and over 20 per cent of the hot-rolled by the new age LADP stainless steels referred to in this paper.

If nickel costs maintain this higher plateau, the market demand for lower-priced available stainless steels will have to be translated into the supply of chromium stainless steel if the industry is to retain its position.

Chromium ores and alloys are abundant commodities with multiple geographic sources and expanding production. The known reserves can serve the needs of the stainless-steel industry for a thousand years. The industry has successfully used substitutes for, or avoided, the short-supply alloys—nickel and molybdenum—but cannot replace chromium.

The first-generation chromium ferritic steels, successful as they were, had serious barriers to acceptance as general-purpose steels. The new generations supercede these barriers, and offer properties that have attracted both the carbon-steel and stainless-steel user industries.

The imperative for participation in the development and marketing of these chromium steels is logical and immediate. It is time for the steel industry to compete aggressively in the new materials field using new products and new concepts.

Long products of 3CR12, an area that has remained relatively untested, are discussed in the Addendum.

The Production Opportunity

The ease and economy of production of the new-generation dual-phase ferritic steels is now established technology. Their ease of production by the producers of both stainless steel and carbon steel is proven. The synergy of stainless-steel technology (in melting, refining, and casting), with carbon-steel rolling technology is a reality.

The process for second-generation 3CR12 eliminates the costly bottleneck of hot-band annealing by controlled cooling, thus freeing valuable continuous-annealing plant capacity. This is a significant facilitator for stainless-steel producers and an incentive for mild-steel producers. The production flowchart to convert a mild steel to the new generation ferritic steel now has one addition—an argon refining vessel—and one subtraction—the hot-band annealing furnace (Figure 3).

The Marketing Opportunity

The marketing horizon has now expanded for stainless-steel producers locked into the cycle of fluctuating over- or under-production, and the rigid demands of specification-bound capital projects.

The opportunity clearly extends into the largest engineering commodity market in the world, the 800 Mt/a carbon-steel market, and a 1 per cent penetration would double stainless-steel production.

The LADP steels provide this opportunity but demand a commitment to constructive market development.

Figures 14 and 15 show how the rapid growth rates of South Africa and Australia are now being attained in Europe, and how current sustained growth can achieve megaton demand if market development is contained on a broadening front. Today, many new plants, structures, and vehicles are showing not only major lifecycle cost benefits but also savings on initial construction costs. The economic arguments are compelling. Typical paybacks are measured in days rather than years, and range from a first cost saving in the case of an integral vehicle to 180 days in the case of a sugar-diffuser baffle plate.

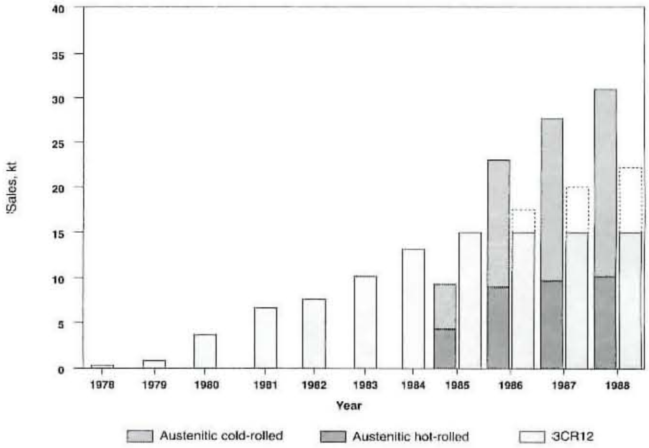

FIGURE 14. Growth of 3CR12 sales in South Africa, 1978–1988

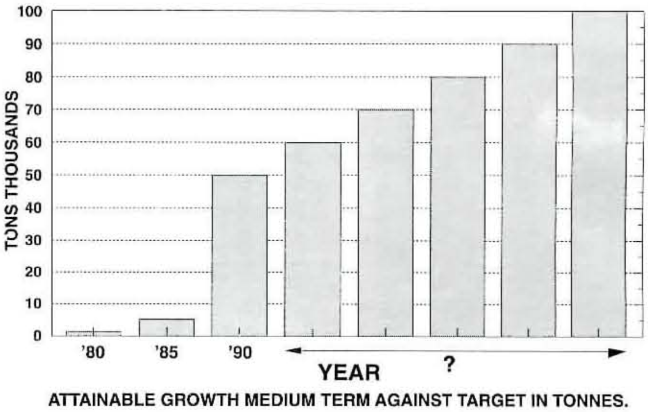

FIGURE 15. Growth of 3CR12 consumption in Western Europe, 1980–1990

Efficient design with this steel makes equipment not only cheaper to run but cheaper to install and safer to operate. This has been confirmed by multiple examples in the sugar, coal, transportation, power, and petrochemical industries, contributing to significant growth in demand over the past ten years.

From Niche to Commodity

Europe's penetration into the lean-alloy market in 1990 was estimated to be over 40 kt of coil plate and sheet. European producers forecast minimum requirements in 1999 at 100 kt, but, with the full use of new technological economies and scales of production, this would approach 1 Mt based on current usage in South Africa, Australia, and Great Britain.

Stainless steel's primary market support originated and continues to be derived from the carbon-steel market. However, inflation, the new nickel plateau, and the trended escalation in prices have now separated these two commodities by additional thousands of dollars, rands, pounds, and Deutsche marks. It is only in Japan that this trend has been inhibited, and it is only in Japan that the growth of stainless steel has been significantly higher than in the rest of the developed world.

The lean-alloy dual-phase stainless steels clearly offer a significant opportunity for growth from niche to major stable commodity.

Addendum: Long Products

An area that has been relatively untested, although having enormous potential for 12 per cent chromium steels like 3CR12, is that of long products. As with flat products, the major target marked is the replacement of carbon steels and galvanized or coated carbon steels.

As the long-product market is widely differentiated, a realistic, quantitative estimate is difficult. Estimates of the South African market for galvanized and carbon-steel long products are shown in Table AI, together with two projections of potential market size for 3CR12.

A 1 per cent projected penetration of the carbon-steel market (equivalent to the current stainless-steel share of carbon steel) would result in a market of some 13 kt/a in South Africa. Worldwide, long products account for some 240 Mt/a. A 1 per cent penetration of this tonnage could result in worldwide sales of some 2,4 Mt/a.

Although the markets for these products are recognized as being exciting, the development of products has been slow owing to the fact that they are primarily produced on carbon-steel mills, where the tooling is already developed. Most stainless-steel mills cannot justify the capital expenditure on rolling mills and tooling to service an embryonic market. Therefore, all the trials carried out to date have been done by means of toll rolling at carbon-steel producers. Approximately 1 kt of 3CR12 long products have been rolled to date on this basis.

A brief description of the trials, market potentials, and associated work carried out in each area follows.

Wire

Approximately 400 t of wire rod in sizes 5,5, 6,0, 7,5, 8,5, and 10 mm have been rolled on three different rolling mills at three different steel companies. In all cases, the rod was successfully rolled without changes to furnace re-heat parameters or mill-roll design. The only modifications were on pass settings to accommodate the different spreading characteristics of 3CR12.

Wire was drawn from the rod, and some problems with drawing were experienced owing mainly to surface quality and descaling—problems that should be readily resolved.

Both weld-mesh fencing and cold-drawn nails were produced successfully from the cold-drawn wire.

Reinforcing Bar

Ribbed reinforcing steel was rolled by two steel plants on three different mills in sizes ranging from 8 to 32 mm. The rolling parameters were as described above, and no undue problems were experienced.

The use of 3CR12 reinforcing bar, wire, or mesh offers exciting prospects for reinforced concrete in coastal or highly corrosive environments owing to the absence of significant corrosion and resulting spalling. Because of the uniform stress–strain behaviour of 3CR12, there may also be some interesting possibilities in ensuring a ductile failure mode of reinforced concrete.

Structural Steel

A variety of hot-rolled structural-steel sections were hot-rolled on a number of rolling mills, once again without major changes to the reheating parameters or roll design.

The products rolled to date are as follows:

Equal angles	*25, 40, 45, 50, 60, 70, 80, 100 mm*
Channel	*100 x 50, 180 x 70, 200 x 75, 30 x 165 mm*
I beam	*100 x 55, 203 x 133 mm*
H beam	*152 x 152, 203 x 203 mm.*

TABLE AI
MARKET FOR SOUTH AFRICAN LONG PRODUCTS

Product	Carbon steel, kt	Galvanized steel, kt	1% carbon steel, kg	5% galvanized steel, kg
Light/medium structural section	800	175	8,00	8,75
Wire	40	30	0,40	1,50
Fencing	105	80	1,05	4,00
Reinforcing bar	330	–	3,30	–
Fasteners	60	4	0,60	0,20
Chain	16	–	0,16	
Nails	17	–	0,17	
	1 368	289	13,68	14,50