Overview of Microalloying in Steel

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1. Introduction

Microalloy (MA) or High Strength Low Alloy (HSLA) steels constitute an important category of steels estimated to be around l2% of total world steel production. They are used in every major steel market sector in various parts of the world and their development has played an important role in the expansion of certain key industries such as oil and gas extraction, construction and transportation.

2. Definitions

Definitions for alloy, low alloy and microalloy steels are given in Table l. The Steel of interest in this seminar is microalloy which contains vanadium, niobium, and/or titanium in amounts at least an order magnitude smaller than the amounts of the normal alloys in alloy or low alloy steels. Despite the low levels of alloying these microalloys can cause major strength and toughness improvements. The obvious economic advance associated with using such small additions together with the significant benefits to mechanical properties are the reasons for the popularity of MA Steels in the market place.

3. Microalloy Steel Development

The historical aspects will be presented as well as the metallurgical basis for Steel development.

3.l. Historical Events

Table 2 reveals the fact that early structural steels were generally of the C Mn type. These early steels contained relatively high carbon contents but this caused no problems in construction since up to the 1940s riveting was used as a means of joining not welding. However even in the l960s the steel in the Melbourne king Street Bridge had fairly high carbon and manganese contents which led to welding problems and subsequent bridge failure. By utilising microalloy steels such welding problems were greatly reduced and a modem offshore steel, produced by a controlled rolling procedure, is shown in the table as a good example of a microalloy Steel. The first national steel standard to allow a microalloy addition was BS 968 in l962 (Fig l) and this resulted in a large reduction in the carbon equivalent value (CEV) combined with an increase in strength.

The first microalloying element to be widely used was vanadium added to C Mn steels in the USA as reported by Bullens in l9l6 (Tab1e 3). Indeed early in the 20th century Hemp Ford made wide use of vanadium steels for the construction of the Mode1 T, the first mass produced motor car. Small titanium additions can also improve the strength of steel and this was first exploited in Germany in l92l. Micro titanium and micro vanadium additions began to be used in China in the l950s and l960s. However the major event that initiated the HSLA Steel revolution did not occur until 1988 when the Great Lakes Steel Corporation of the USA began production of low C Mn steels microalloyed with niobium. This event created widespread interest among the world's steelmakers leading to the rapid deve1opment of HSLA Steels containing the microalloys vanadium, niobium and titanium either singly or in combination.

3.2. Metallurgical Factors

A fine grain sire is all essential requirement in most HSLA Steels to obtain the necessary strength and toughness properties. Figure 2 shows the relationship between grain size and yield Strength in C Mn steels and a similar relationship exists between grain size and fracture toughness. A fine grain sire around l0 μ m in a low carbon steel obtained by controlled rolling or heat treatment provides excellent mechanical properties to which further strength can be added by making microalloy additions giving precipitation hardening.

The various functions performed by the microalloying elements are described in Table 4. All perform well in providing precipitation strengthening after the hot rolling of C Mn steels, vanadium being especially versatile in this respect, and they also all provide grain refinement after a nonmalising heat treatment. However other roles are more characteristic of certain microalloying elements. For example a vanadium addition is able to give precipitation strengthening in high carbon stee1s, niobium has a particularly strong influence in reducing the recrystallisation during hot rolling thus aiding grain refinement and a small titanium addition is very effective in refining grain size at high temperatures in the austenite range.

The choice of microalloying element to use in a steel is strongly influenced by the solubility of the microalloy carbide or nitride. (Fig 3) For example because vanadium carbide is relatively soluble in steel, vanadium is used to strengthen higher carbon steels while vanadium nitride has d powerful effect in increasing strength in steels with enhanced nitrogen contents. (Fig 4). The fact that vanadium has relatively little or no influence on transformation characteristics after hot rolling can be beneficial in providing acceptable properties over a wide range of finish rolling temperatures as occurs particularly in the rolling of sections. On the other hand niobium has a major affect on transformation which can cause the formation of a brittle microstructure (Fin 5).

One of the main benefits of niobium, that it reduces the rate of recrystallisation of austenite during hot rolling (Fig 6), is utilised in the controlled rolling of HSLA Steel to improve grain refinement. Since close control over processing is required this is normally practised in plate and hot strip rolling halls. Thus niobium has become an important addition to controlled rolled line-pipe stee1s often in conjunction with the other microalloying elements. The improvement in line-pipe grades as a result of microalloying and advanced processing techniques is illustrated in Figure 7. An early line-pipe Steel was vanadium treated in the normalised condition but thereafter the grain refinement, necessary for improving properties, was obtained by controlled rolling a niobium treated steel with vanadium added for increased strength. Further improvements allowing steel grades to reach X80 and Xl00 properties have been made by utilising multi additions of microalloys together with accelerated cooling after controlled rolling.

One of the main roles of titanium in modern HSLA Steels is that of maintaining a fine grain size at high temperatures in the austenite range (Fig 8), for example during reheating prior to rolling and in the heat affected zone of weldments. Titanium is usually combined with vanadium and/or niobium as is the case with a recently developed vanadium-titanium steel designed to give grain refinement during hot rolling without the need to control to low finish rolling temperatures. It is important to ensure that additions of microalloying elements to steel are carefully planned to ensure that the desired effects on properties are obtained. For example research has shown that the amount of titanium added to a steel must be controlled to maximise the formation of fine titanium nitride particles and to avoid the formation of large particles which can exert a harmful influence on fracture properties.

4. Market size

It is estimated that of the nearly 800 Mt of steel produced in the world today about 12% could be defined as HSLA. Such steels are used in all major market sectors especially line-pipe and offshore (Table 5). They are used to different degrees in the various parts of the world. For example HSLA Steels are extensively used for both shipbuilding and pressure vessel purposes in Japan much more so than in Europe and North America. A growth opportunity for microalloyed steels is in the automotive sector as manufacturers strive to reduce the weight of vehicles.

5. Advantages and Disadvantages of HSLA Steels

Assuming that design codes allow it, normal Steels can be replaced with HSLA Steels resulting in a saving of the amount of steel used. Fabrication costs can be reduced when HSLA Steels are used due to savings in transport and handling and in welding (Fig 9). Another advantage related to the use of HSLA Steels is from operational savings due, for example, to increased pumping capacity in line-pipe and to propulsion energy savings in ships (Fig 10).

Although far outweighed by the advantages there are also some disadvantages associated with the use of HSLA Steels. Their use is limited due to design factors such as structural rigidity requirements and the fatigue strength of welded joints. Also the corrosion rate can be a limiting factor unless precautions are taken to obviate it such as applying special protective coatings to the steel.

6. Trends in Properties/Processing /Composition

The following trends are aimed at maintaining and improving the strong market position of HSLA Steels.

- More closely controlled composition
- Reduced carbon content
- Increased combination of microallay elements
- Lower residuals and improved cleanness
- More sophisticated processing
- Increased uniformity of properties
- Minimal heat treatment
- Improved shape and surface appearance
- Higher strength and improved fracture properties
- Better weldability and weldment toughness

Table 1

Definitions

Alloy Steel	Steel containing significant quantities of alloying elements (other than carbon and the commonly accepted amounts of manganese, silicon etc.) to effect changes in the mechanical or physical properties.
Low alloy Steel	Steel containing less than 3.5% of alloying elemens e.g. 2.25%Cr 1%Mo.
Micro Alloy Steel	Steel containing small amounts of vanadium, niobium and/or titanium. Individual elements generally less than 0. 10% and total microalloying elements generally less than 0. 15%. Also known as HSLA steels.

Table 2

Example of structural steel compositions over past 100 years (19mm plate min. YS 355 MPa)

STRUCTURE	C	Si	S	P	Mn	Cr	Al	Nb	CEV
Forth Rail Bridge (1890)	0.23	0.02	0.024	0.046	0.69	*	*	*	0.35
Sydney Harbour Bridge (1929)	0.34	0.20	*	*	1.00	*	*	*	0.51
Melbourne King Street Bridge (1961)	0.23	0.19	0.026	0.017	1.58	0.24	<0.005	*	0.54
Offshore UK (1994)	0.08	0.31	0.002	0.012	1.41	0.027	0.034	0.028	0.32

Table 3

History of microalloying

Element	Level, wt%	Country	Date	Yield Strength, N/mm^2
Vanadium	0.10 - 0.20	USA	1916	275 - 345
Vanadium	0.10	Germany	1945	> 390
Niobium	0.02 - 0.03	USA	pre 1959 (patent 1940)	325 - 445
Niobium	0.005 - 0.05	Britain	1959	350 - 425
Titanium	0.10 - 0.20	Germany	1921	260 - 550

Table 4

Roles of microallying elements

Microalloy	Precipitation Strengthening after Hot Rolling	Precipitation Strengthening after Normalising	Influences Recrystallisation during Hot Rolling	Refines Grain Size on Normalising	Refines Grain Size during High Temperature Austenitising	Influences Transformation Characteristics after Hot Rolling
V	VN, VC	VC		VN	-	-
Nb	NbCN	-	Nb, NbCN	NbCN	-	Nb
Ti	TiC	-	-	TiC	TiN	-

Table 5

Proportion of HSLA steels produced world-wide(%)

	Europe	**N. America**	**Japan**	
Linepipe	95	95	95	
Shipbuilding	40	20	75	
Offshore Steels				
Plates	90	30	70	
Sections	70	20	10	
Pressure Vessels	30	25	85	
Structural				
Sections	30	20	10	Annual World Tonnage ～800Mt HSLA Steels～12%
Section, automotive	80	80	80	
Section, ships	15—30	20	10	
Sheet pilling	25	15	100	
Rebar	100	5	10	
Plates	25	20	10—30	
Sheet and Coil (inc. Galv.)				
Automotive	30	20	30	
Building (not rebar)	95	80	70	

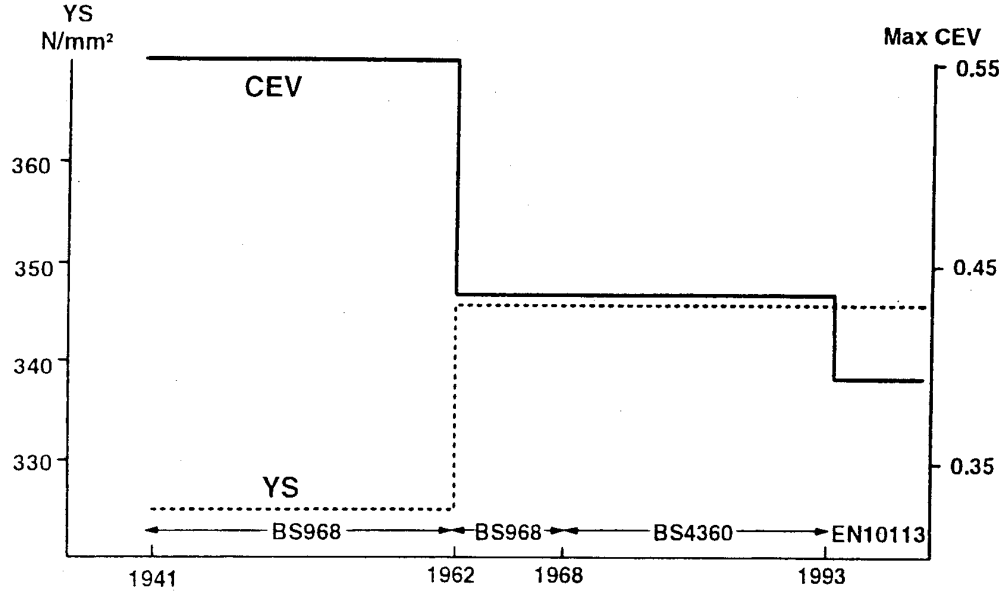

Figure 1 Evolution of structural steel standard BS 968 due to microalloying

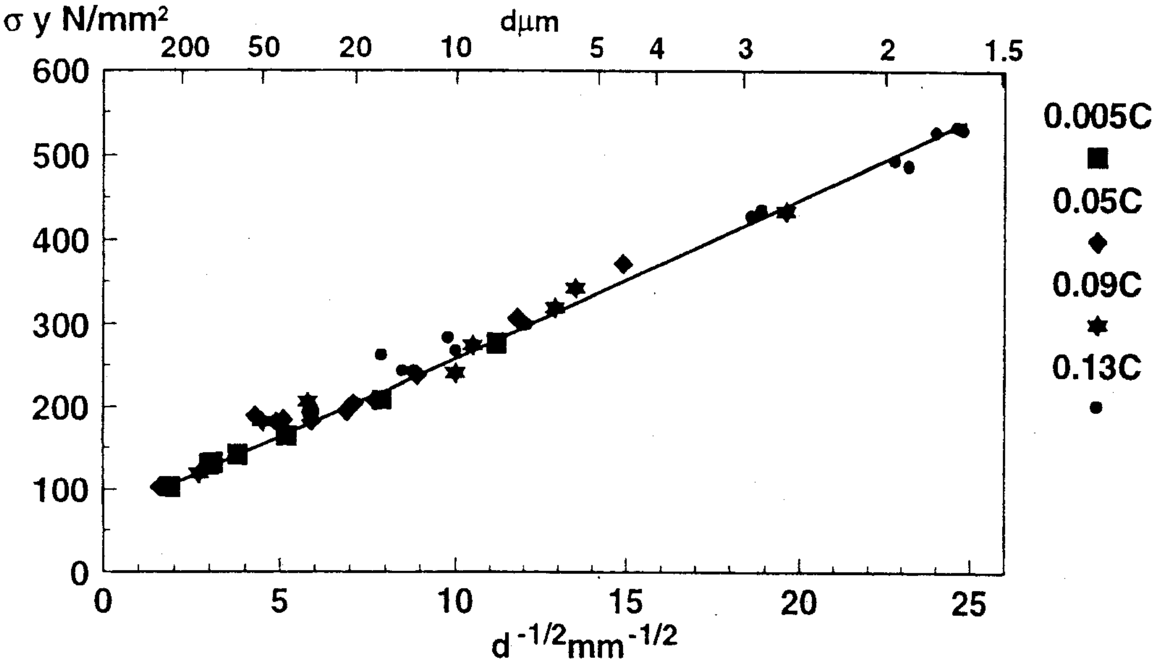

Figure 2 Relation between lower yield strength and the inverse square root of the grain diameter

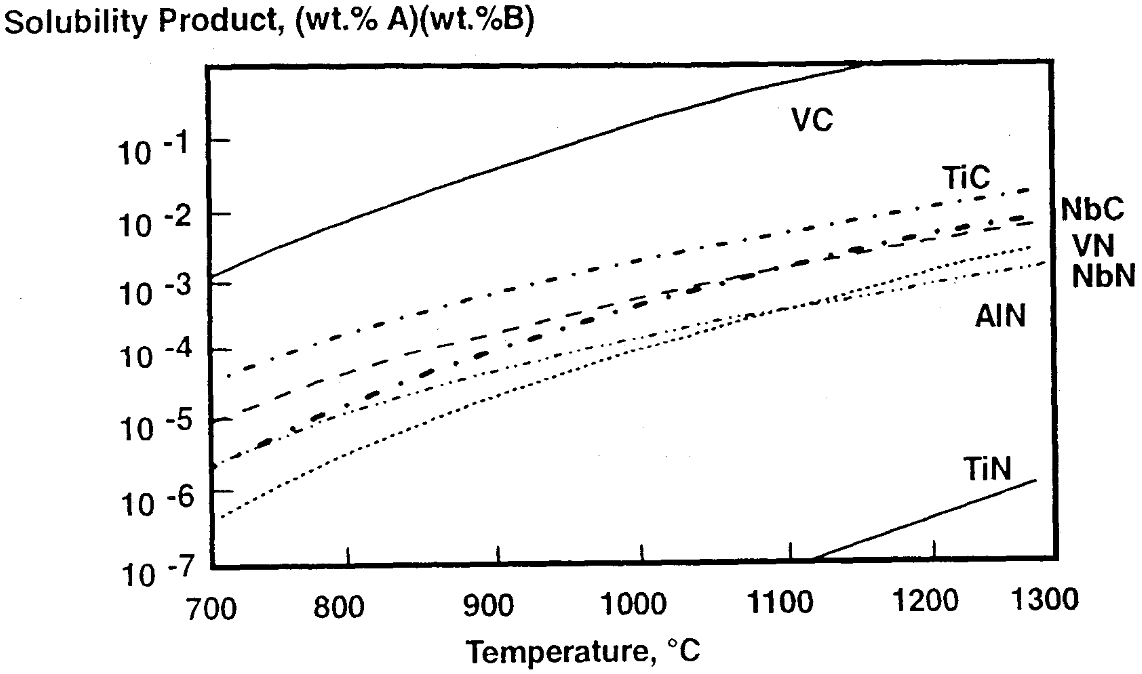

Figure 3 Solubility of microalloy carbides/nitrides

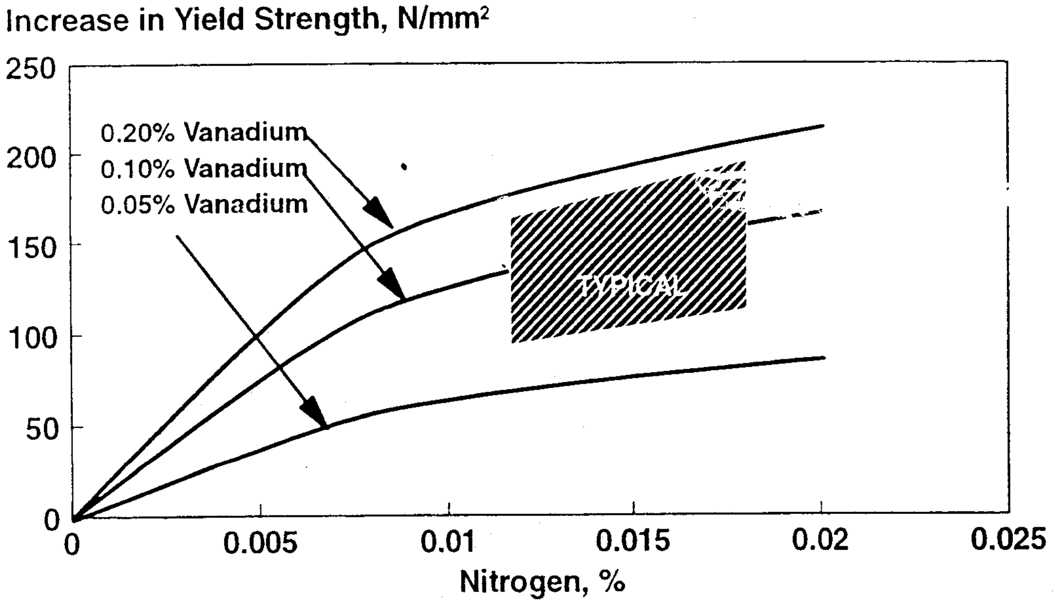

Figure 4 Increase in yield strength from vanadium and nitrogen in a hot coil product as a result of the precipitation of vanadium nitride

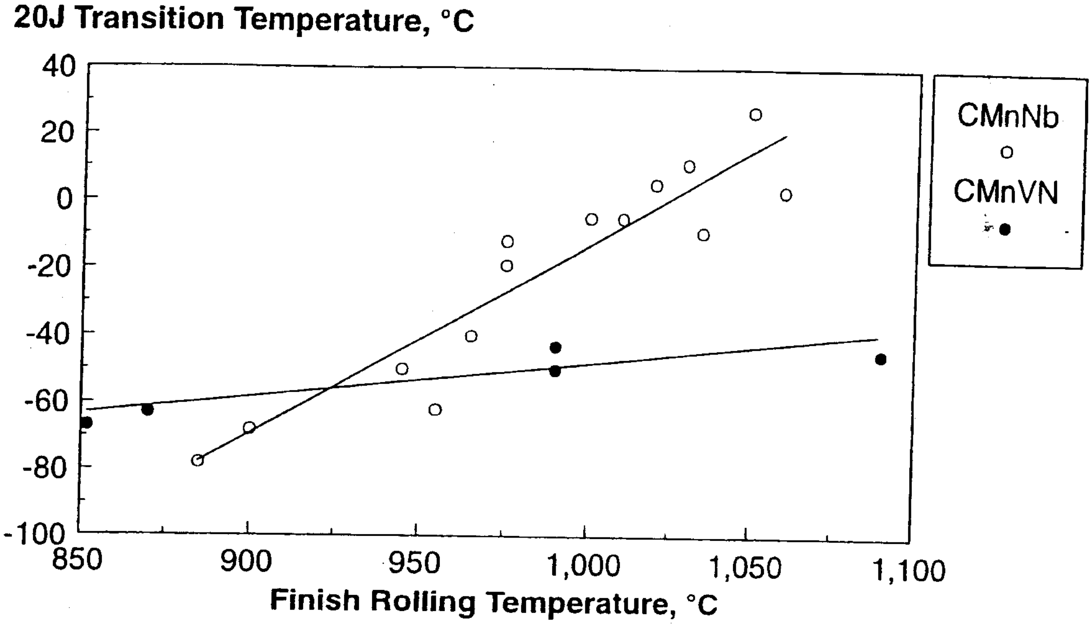

Figure 5 Influence of finish rolling temperature on impact transition temperature for niobium and vanadium C Mn steels

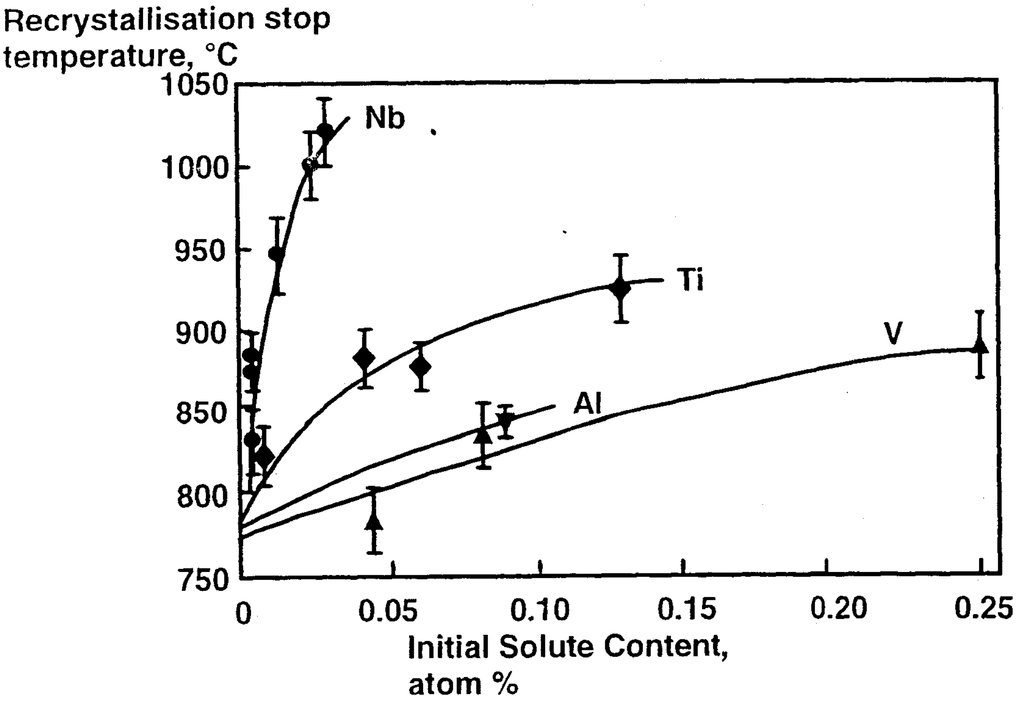

Figure 6 Influence of microallys on the recrystallisation of deformed austenite

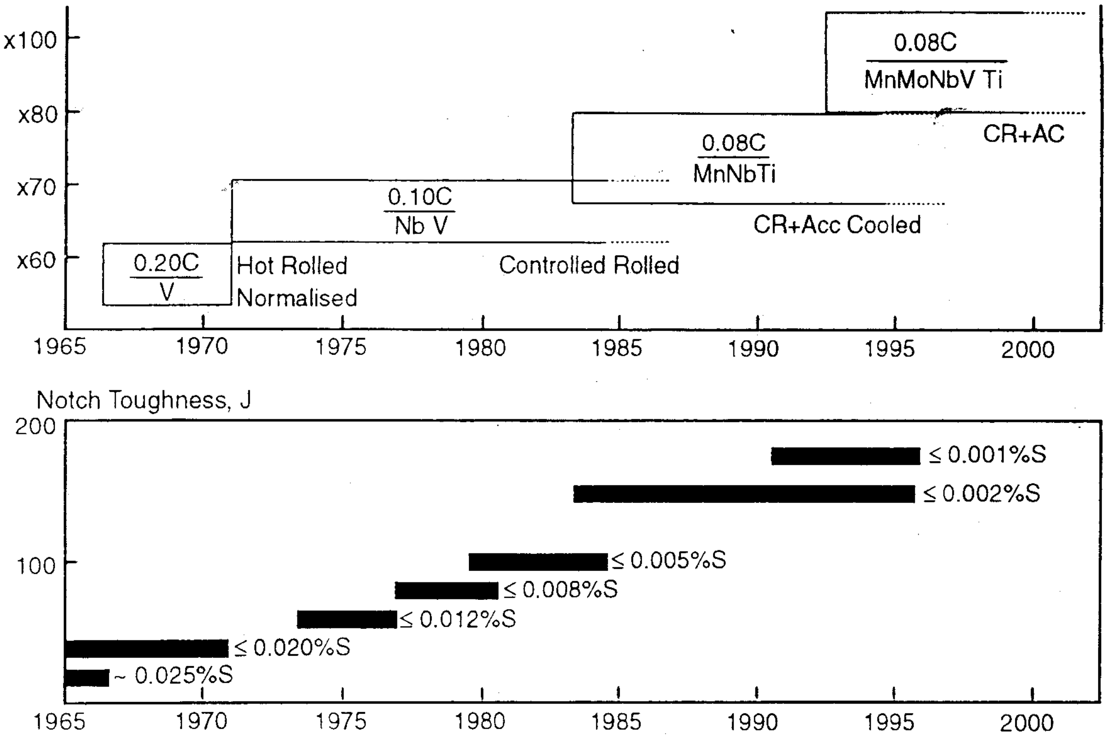

Figure 7 Development of line-pipe steels

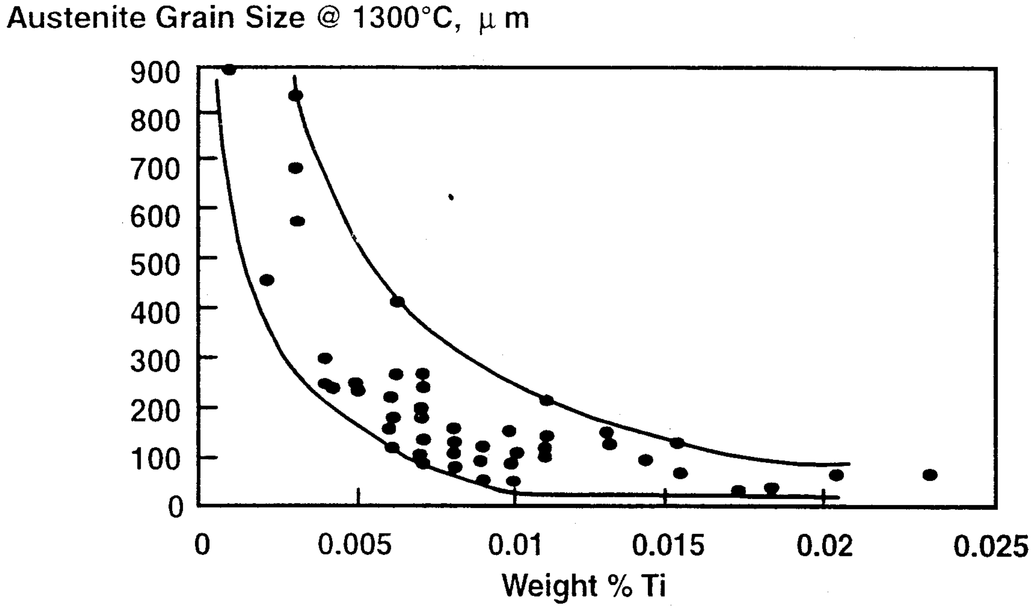

Figure 8 Effect of titanium content on austenite grain size at 1300℃

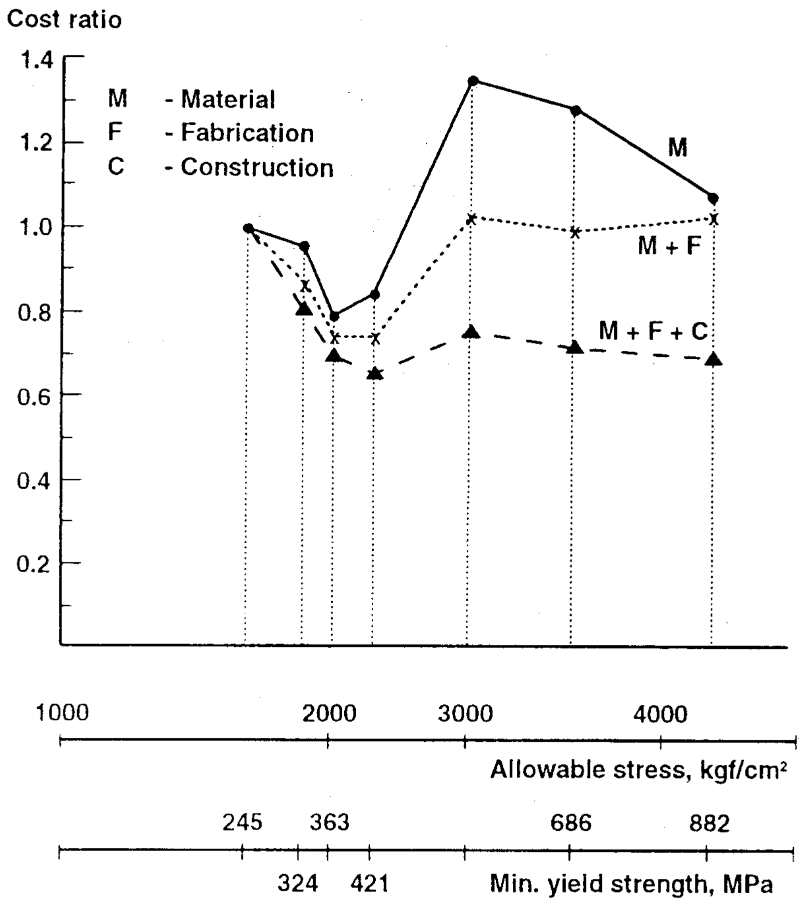

Figure 9 Cost reduction with increased strength for a bridge construction

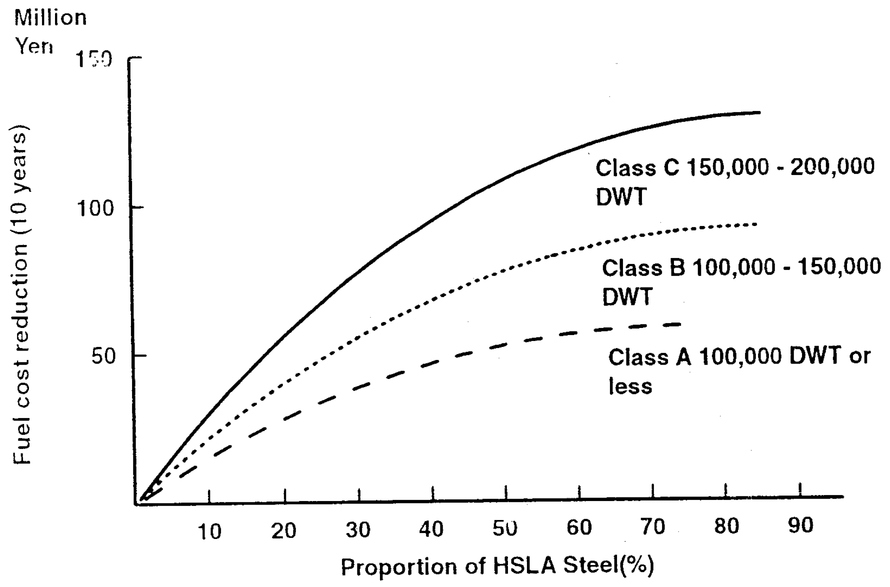

Figure 10 Reduction in fuel costs of HSLA steel based ships