

Development and Use of Vanadium in Micro-Alloyed Reinforcing Bar

D. Russwurm

Dr.-Ing. habil.

Managing Director of German Institute for Reinforcing Steel

Introduction: Importance of Reinforcing Steel

Reinforcing steel is one of the main steel products worldwide produced and used. In 1998 the world consumption of reinforcing steel was about 95 Mio tons. Compared with the total steel production at that time about 13 % of steel was dedicated for the reinforcement of concrete. A comparison between cement and reinforcing steel for the globe and for Europe is shown in Fig. 1.

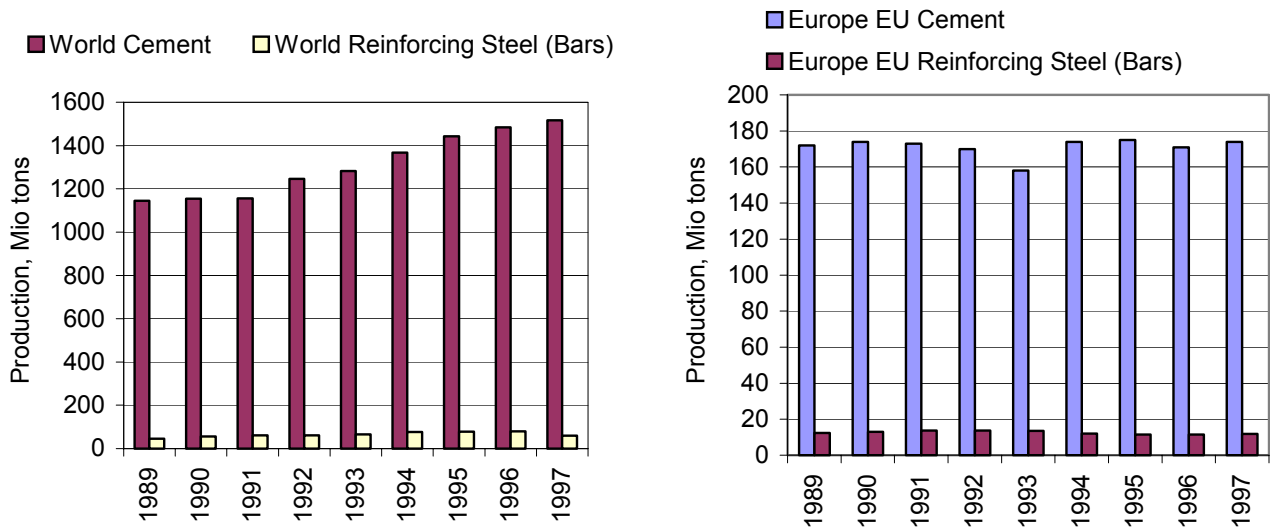
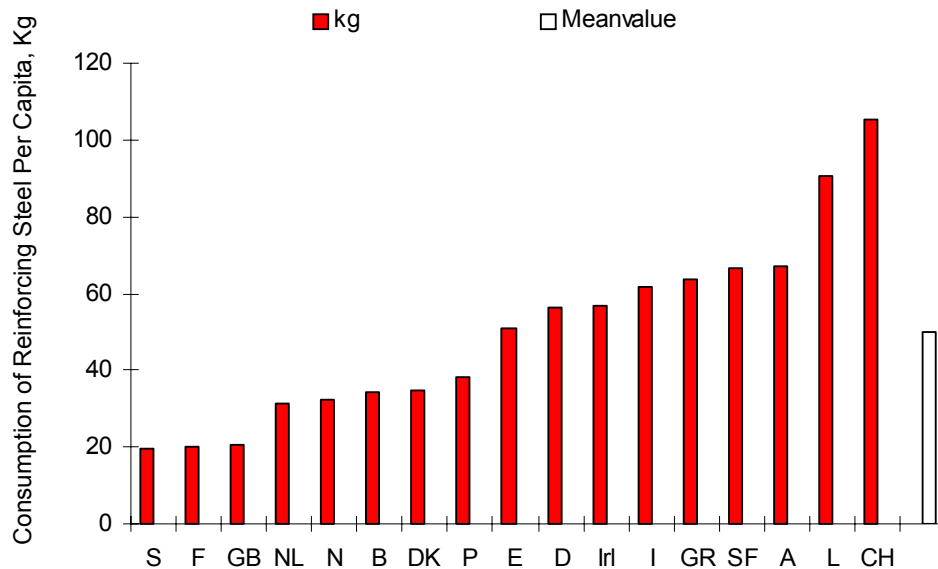


Fig.1. World and European Production of Cement and Reinforcing Steel.

By the way the consumption of cement – the second of the construction materials in the compound system “steel – concrete” is round about 1,6 billion tons. This results in a portion of ca. 20 kg of reinforcing steel per m³ of concrete.

This makes it clear that reinforcing steel is strongly depending on the amount of reinforced and prestressed concrete which is without doubt the leading construction method in all continents of the world.

But the consumption differs from country to country. Fig. 2 shows the consumption per capita and year of reinforcing steel of some European countries.



The differences are caused by the design-codes – some are reinforcement friendly, some not – the topographical situation – expensive constructions e.g. in traffic buildings – and the preference for a construction method.

Generally can be said that for different reasons as reinforced concrete will remain for this and the next generation will remain the leading construction method. But will be steel also remain the dominating reinforcement. I am sure you have heard a lot of non-ferrous reinforcements as carbon and glass or a Aramid.

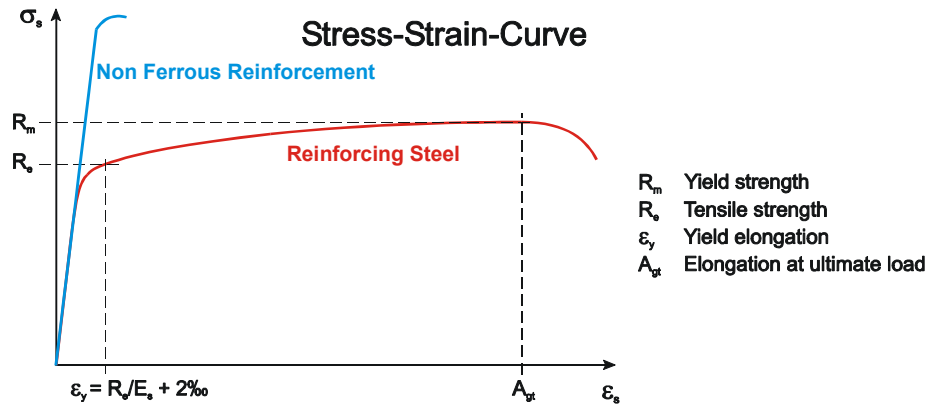
The advantages of steel are evident. Some of them are listed up in the following figures.

“Reasons for Steel as Optimal Reinforcement for Concrete”

- Load transfer has to be performed from concrete to reinforcement and vice versa over a limited development length
- The reinforcement has to have a high modulus of elasticity in order to gain a high degree of stiffness for the construction as a whole.
- The interaction between concrete and reinforcement must be in terms of chemical and physical phenomena free of disadvantages.
- The reinforcement must have the appropriate delivery forms, shape and length which fit with the various constructions.
- Spacious interfaces, e.g. sheets are less suitable in comparison with rod-formed elements which are offered in a great variety and a large range to match the calculated values of reinforcement section.
- The reinforcement has also to match with the shape of the construction; it must be flexible and easily bendable.
- The reinforcement must be capable to be joint, either by overlap or particular joining techniques as welding, forming mechanical connections.
- The reinforcement has to resist without significant deterioration of damage the rough conditions during transport, storage, bundling and placing on job site. Minor damages should not reduce significantly the performance characteristics.
- The reinforcement of prestressed constructions (prestressing steel) has to assure that no sudden and brittle collapse due to corrosion attack takes place.
- The reinforcement has to provide to the construction a sufficient fatigue resistance because concrete is not resistant to dynamic loading.
- The reinforcement has to attribute to the construction a sufficiently high ductility behaviour.
- The reinforcement has to resist shear forces as well as tension and compression forces.
- The relaxation of prestressing elements has to be suitable low.
- The reinforcement must offer its performance characteristics in a sufficient range of temperatures (- 60 °C to + 80 °C). In case of extreme low or high temperatures (fire) the behaviour of the reinforcement must be predictable.
- The quality level of the reinforcement has to be usually such to be able to compensate minor imperfections in the execution of the construction.

Some disadvantages of the non-ferrous products are also obvious (Fig. 5):

Fig. 3. Comparison Steel – Non Ferrous Products



- absolute brittle material
- low-E-modulus
- not bendable

Nevertheless what we need is

- a high quality steel
- a steel fit for usual handling at the manufacturers and on job site
- and a steel which is perfectly adjusted to all design methods of the civil engineers.

About this steel I want to speak to you today. The structure of my presentation is the following:

Development and Use of Vanadium in Micro-Alloyed Reinforcing Bar Advantages of High-Strength-Steel

Introduction: Importance of Reinforcing Steel

Mainly used types of reinforcing steel

Important performance characteristics

Production methods

 Cold working

 Heat treatment

 Micro-alloying

Economical Aspect

Metallurgical Aspects

Economic advantages of high strength steel Savings due to high yield reinforcement

Ecological Aspects

Summary

Mainly used types of reinforcing steel

To describe very briefly the mainly used typed of reinforcing steel I refer to the leading standards on this field. These are:

USA: ASTM 615 / ASTM 706

UK: BS 4449

Germany: DIN 488

Europe: Draft of prEN 10080 / prEN 10081

USA:

Concerning reinforcing steel the US are not at the frontier of the development. The standard includes two grades with the minimum yield levels of

300 N/mm² and 400 N/mm².

Generally the bars are deformed that means with high bond properties. This grades are not weldable and have no specific ductility requirements apart from bendability and no specifications concerning fatigue.

The second standard which covers weldable grades is up to date also with the grades (yield strength) 550 / 540 and 420 N/mm². The consumption of these grades is far below ASTM 615 grades.

United Kingdom:

The BS 4449 gives the specifications for the British reinforcing steel. The main grade is a steel with minimum yield of 460 N/mm². This steel has to be weldable, is provided with high bond and can be used under cyclic loading.

Germany:

The German standard DIN 488 knows two grades with yield strength 420 and 500 N/mm². Since round about 16 years exclusively the minimum yield 500 N/mm² is used with great success in all applications as

- bars
- coils
- wire fabric
- lattice girders.

Other European Countries:

The range of yield strength is spread between 400 to 700 N/mm². nearly all grades are weldable.

European Standardisation:

The work on European Standard for reinforcing steel is still going on. Due to an intervention of the European Commission we will probably get a harmonised standard without defining steel grades.

As chairman of the committee ECISS TC 19 I did not succeed to implement only 3 grades with yield strength 500, respectively 450, which would have been a great success in comparison with the existing 47 grades in the different member states.

A summary shows what the up-to-date steel grades have:

Standard	Yield Strength N/mm ²
ASTM 615	400
ASTM 706	550 / 420
BS 4449	460
DIN 488	500
Europe (general)	400 to 700
Weldable steel (generally in Europe)	
Fatigue resistant (generally in Europe)	

I mention this important features because they play an important role for the production routes later have to be discussed.

Important performance characteristics

The reinforcing steels have no use for themselves they depend from their application in concrete.

The usual design codes differ under the aspect of using the reinforcement according to their systems of structural analysis. There are different methods of structural analysis which require different properties of the reinforcement (Fig. 8):

- linear elastic analysis
- linear elastic analysis with limited moment redistribution
- plastic methods of analysis
- non-linear analysis
- earth-quake design with energy dissipation
- fatigue resistance

Corresponding to the applied method the requirements of the reinforcing steel differ.

Additionally the serviceability limit state of a building has to be taken into account as

- crack formation, limitation of crack width

- limitation of deformations

Further on durability of a construction, in modern words the sustainability touches the required properties of steel.

In order to obtain a good rationalisation in producing solid cages of reinforcement and to perform splices weldability is of greatest interest.

How the requirements interact with the desires of the designers is shown in Table I:

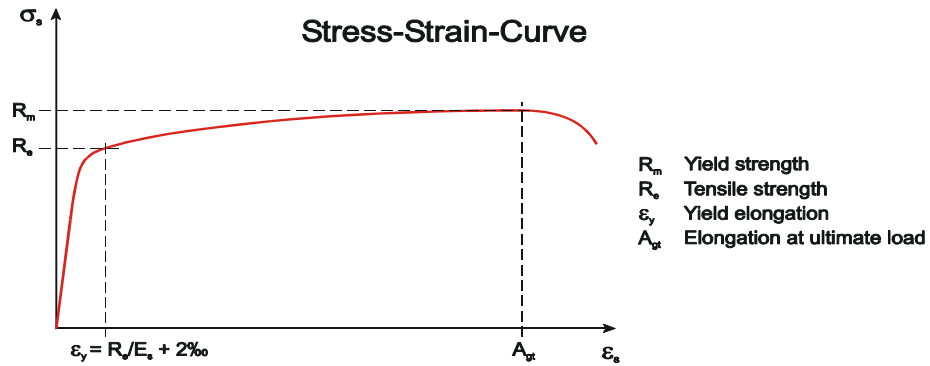
Basis of Demands	Resulting Requirements of Reinforcing Steel
Competitiveness of reinforced concrete	Yield as high as possible
Structural analysis: linear elastic and moment redistribution plastic methods non linear earthquake design fatigue	high yield high yield and ductility high yield and high ductility high yield and high ductility sufficiently high yield in combination with highest mobility requirements high yield and fatigue resistance
Serviceability limit state	Yield strength adjusted to crack control and acceptable deformations
Sustainable constructions	Corrosions resistance
Handling of reinforcement	Bendability, Rebending, Weldability

Some requirements have to be explained and defined.

Yield strength is obviously clear. Ductility needs to be clarified.

In Fig. 4 a stress-strain-curve gives the answer:

Fig. 4. Stress-strain Curve showing Ductility



Designers use two parameters to define ductility R_m/R_e and A_{gt} .

Now the different reinforcing steels provide various values.

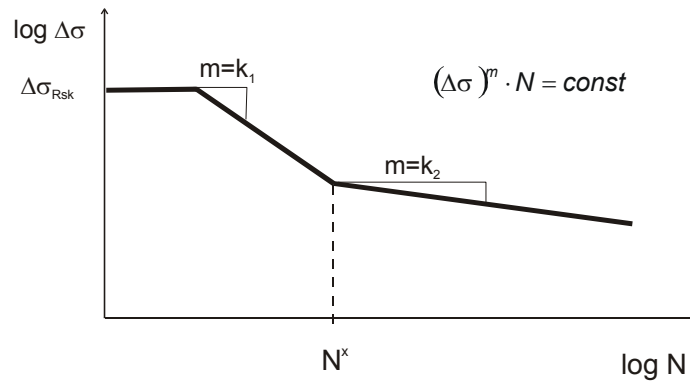
Among them 3 groups have been formed (Table II):

Table II

	R_m/R_e [-]	A_{gt} [%]	Type of steel
Normal ductile steel	1,05	2,5	cold worked
High ductile steel	1,08	5,0	hot rolled (heat treated, micro-alloyed)
Earth-quake steel	1,15 ($R_{e,act}/R_{e} < 1,3$)	8,0	hot rolled (heat treated, micro-alloyed)

Fatigue resistance is defined by an SN-line (Fig. 5):

Fig. 5. Fatigue Resistance Defined by SN Line



Normally only one point (point of intersection) is given in the standards, expressed by the stress range and the number of load cycles. Sufficiently high values for reinforcing steel are round about 200 N/mm^2 at $2 \cdot 10^6$ load cycles (see Table III):

Product Form	Bars and de-coiled rods	Wire Fabrics	Requirement of Quantile Value
Fatigue stress range ($N \cdot 10^6$)[*] (N/mm^2) with an upper limit of not more than $0,6 f_y$	150	100	10
*) This fatigue requirement is not required for predominantly static loading. If higher values are shown by testing and approved by an appropriate authority, the design values (table 6.3) may be modified. Such testing should be in accordance with EN 10080.			

Weldability for reinforcing steel is a complex problem: the number of splices are limited: but the types are very sensible for load transfer. The production routes for reinforcing steel have to be also respected. (See Table IV)

Table IV. Permitted Welding Methods and Examples of Application

(see EN ISO 17760)

**Permitted welding methods and examples of application
(see EN ISO 17760)**

Loading case	Welding method	No.	Bars in tension ¹	Bars in compression ¹
Predominantly static	flash-welding	24	butt joint	
	manual metal arc welding and metal arc welding with filling electrode	111	butt joint with • • 20 mm, splice, lap, cruciform joints ³ , joint with other steel members	
		114		
	metal arc active welding ²	135	splice, lap, cruciform ³ joints & joint with other steel members	
		136		
	friction welding	42	butt joint, joint with other steels	
resistance spot welding (with one-point welding machine)	21	lap joint ⁴ cruciform joint ^{2,4}		
Not predominantly static	flash-welding	24	butt joint	
	manual metal arc welding	111	-	butt joint with • • 14mm
	metal arc active welding ²	135 136	-	butt joint with • • 14mm
Notes:				
1. Only bars with the same or similar nominal diameter may be welded together.				
2. Permitted ratio of mixed diameter bars • 0,57				
3. For bearing joints • • 16 mm				
4. For bearing joints • • 28 mm				

The definition of weldability for reinforcing steel is worldwide meanwhile uniform, it consists of

- a carbon equivalent value
- limitations of pass percentage of some elements

Table V shows the most common values

Table V. Chemical composition (% by mass)

	Carbon ^b (max)	Sulphur (max)	Phosphorus (max)	Nitrogen ^c (max)	Carbon Equivalent Value ^b (max)
Cast analysis	0.22	0.05	0.05	0.012	0.50
Product analysis	0.24	0.055	0.055	0.014	0.52

a Max 0.80% by mass Cu permitted

b It is permitted to exceed the maximum values for carbon by 0.03% by mass, provided that the carbon equivalent value is decreased by 0.02% by mass.

c Higher nitrogen contents are permissible if sufficient quantities of nitrogen binding elements are present.

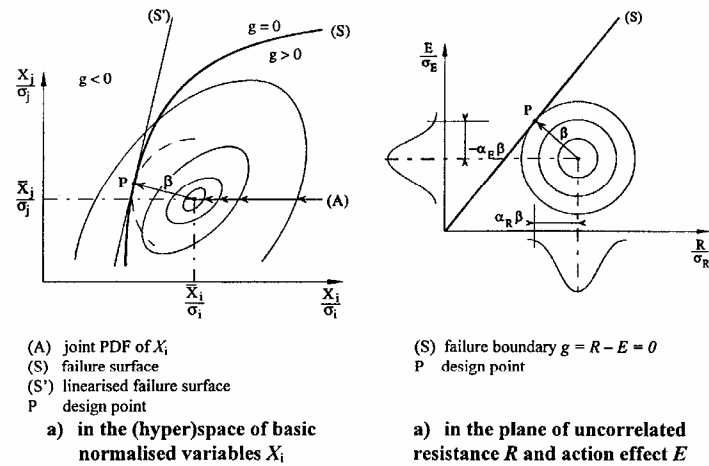
Please, note that concerning micro alloying elements there is some freedom in the application in combination with nitrogen.

Finally I mention bendability which is a basic demand of all manufacturers. It has to be seen in dependency of the notch effects of the ribs which are responsible for the bond behaviour.

Everybody knows that all constructions have to be safe. The safety of a bridge and a building has in any case to be given even if overloading and exceptional cases like explosions etc. take place.

The safety philosophy currently mainly used in design are semi probabilistic methods (Fig. 6)

Fig. 6. Design Point and Reliability Index β According to the First Order Reliability Method (FORM)



Design point and reliability index β according to the first order reliability method (FORM)

From the part of the building materials one expects significant contributions to the safety of a construction. The mathematical interpretation of this contribution is the so-called

partial-safety-factor γ_s .

Based on a log-normal distribution of the property e.g. the yield strength the formula reads as follows:

partial-safety-factor

$$\gamma_s = \exp[(\alpha \cdot \beta - v) \cdot k]$$

$$\alpha = 0,8$$

$$\beta = 3,8$$

k = quantile coefficient

$$v = \frac{\text{standard deviation}}{\text{average value}}$$

where v is the coefficient of variation, the quotient between standard deviation and average value.

$$v = \frac{s}{\bar{x}}$$

It is clear that the larger v is, the higher the γ_s -value becomes and the risk increases. Low values of v provide constructions with an additional “hidden” safety which more than one believes will be used.

Another property of minor importance with reinforcing steel is corrosion resistance.

This problem has to be subdivided into two aspects

- corrosion before placing and pouring concrete
- corrosions of steel embedded in concrete.

In the first case slight corrosion is not dangerous, it improves bond; pitting corrosion has to be avoided.

Much more problematic is corrosion in concrete. One tries to avoid that by requirements for concrete density and concrete cover. Under exceptional condition as marine surroundings stainless steel, galvanised or Epoxy-coated steel is demanded.

In the next chapter I will show you in which advantageous way these basic and important performance characteristics depend of micro-alloying because of the fact that there are clear interactions with the metallurgy of the steel.

Production methods

The very first steels used as reinforcement were profiles or rounds which are hot rolled ferritic, perlitic steels on the basis of carbon and manganese.

Rather soon engineers detected that cold working improves the resistance, but decreases dramatically the ductility; for simple design no problem.

Some twenty years ago microalloying in grade 400 and 500 N/mm² appeared on the market. Parallel to that heat treated bars were developed.

The current situation concerning product and delivery form is shown in Table VI

Table VI

Product Delivery Form	Sizes mm	Yield strength N/mm ²	Ductility	Weldable	Production Route
Bars	12 ÷ 40	400 ÷ 450	high	-	hot rolling
	12 ÷ 40	400 ÷ 600	high	+	micro alloyed, heat treated
Wires	< 14	≈ 500	normal	+	cold worked
	< 14	≈ 500	high	+	hot rolled, stretched
Wire fabric	< 14	≈ 500	normal	+	cold worked
	< 14	≈ 500	high	+	hot rolled, stretched
Bars	> 40	≈ 500	high	+	combination of micro alloying and heat treatment
	12 ÷ 40	400 ÷ 500	extreme	+	mainly micro alloyed eventually heat treated

Cold working of large sizes has been important in the past but disappeared totally due to economical reasons.

For bars currently two routes are in competition: micro alloying and heat treatment.

There are three fields of production where heat treated material cannot be used:

- small sizes produced in fast-running rolling mills for wires, speed > 60 m/sec

- large sizes (> 40) in grades ≥ 500
- extreme ductility requirements.

A survey how the micro alloying production route influences the performance characteristics of reinforcing steel is given in Table VII.

Table VII

Performance Characteristics	Favourable Reasons to Use Micro-Alloyed Reinforcing Steel
Yield strength	Perfect way of increasing yield by precipitations and grain size
Ductility R_m/R_e A_{gt}	$R_m/R_e \geq 1,15$ independent form size Elongation at maximum load $\geq 10\%$
Fatigue	Reduction of notch-effect at tib-basis due to fine grain improvement due to homogenous structure – no embedded martensite / ferrit
Weldability	Improved particularly at butt-welds due to homogenous resistance across the section
Safety	Coefficient of variation small due to smaller standard deviation leads to higher safety
Bendability	Lower notch effects at ribs results in smaller mandrills for bending
Corrosion resistance	Amount of corrosion before concreting and later is small due to rather dense layer of mill scale on the surface
Behaviour in case of fire	Smaller decrease of yield depending of temperature (significant ≥ 700 °C; cold worked 400 °C; heat treated: 550 / 600 °C)
Machining and mechanical splices	Machining (lather operating) possible; splices with threads do not reduce resistance
Mechanical defects on surface	No influence on resistance, notches are softened by fine grain size

If one regards all performance characteristic and all handling practice micro alloyed reinforcing steel has superior behaviour in comparison with reinforcing steel produced according other production routes.

Economical Aspect

Reinforcing steel as a mass product has to be cheap. Further on the production should not be linked with large numbers of defective heats: a zero-defect production is the precondition for economical and efficient production.

Rebars after leaving the rolling mill have to be fit for use without finishing process. This means that for bars a discontinuous cold working process after hot rolling as Rippentorstahl (twisted bars) did it – is completely out.

A usual production of reinforcing steel is done in so-called mini-mills with a production of 0,5 to 1,5 million tons annually. These mills use electric arc furnace process with ladle metallurgy continuous casting systems and usual mill trains. High investment for additional equipment is not desirable. Further an immediate start of a new product should be possible without long transition and practising time.

A complete installation of a heat treating equipment for all sizes of bars and round 1 million tons per year has costs of 3,5 million \$.

One needs a sufficient large space between the last stand and the cooling bed. Additional scissors for bars of high shear resistance are necessary and the abrasion of conveyers etc is rather high. One needs also the installation of a temperature control system, that means additional quality control.

Using the micro alloying process one is able to switch over from traditional hot rolled low yield bars to high yield weldable and ductile steel.

Metallurgical Aspects

The production of EAF-steels – particularly for reinforcing steel – is expected to rise significantly. These steels are inherently high in nitrogen for which in most standards upper limits (120 ppm) are given. The standard permit on the other hand be exceed the above mentioned value if sufficiently high degrees of nitrogen binding elements.

Practise has shown that among the N-binding elements Vanadium is the most effective to use nitrogen as a strategic alloying element to obtain best mechanical

properties. Own experiences e.g. with Titanium give an extremely high standard deviation due to the rolling conditions. The optimised properties result from fine ferrite grains if multiple deformation steps in the austenite zone take place. Further precipitation strengthening can also be achieved in the steels after ferrite formation.

Thus of the different nitrogen binding elements in consideration, Vanadium offers the best and most efficient possibility for eliminating harmful effects from nitrogen and substantially helps to use nitrogen as a strategic alloying.

The effect of vanadium and nitrogen can be enhanced by the use of a nitrided vanadium alloy.

If one compares a steel with the same level of vanadium obtained by FeV or the use of nitrided vanadium alloy the yield increases by more than 120 N/mm^2 in using VN. This results logically also in a decrease of the cost of production. The advantage of adding N-enriched nitrided vanadium alloy is caused by the fact that it promotes the precipitation of vanadium which has a significant influence on the decrease of wasted vanadium dissolved in the matrix.

As already explained in Chapter "Production Methods" the optimised demanded performance characteristics for reinforcing steel have to be seen in close connection with small grain size and precipitation of fine V (C,N). By that particularly the properties like ductility and fatigue resistance as well as weldability are positive influenced.

The common production process is not negatively influenced that means no specific changes the technology are necessary. In comparison with heat treated steel no expensive installations have to be financed.

Economic advantages of high strength steel

Savings due to high yield reinforcement

A very particular and most important aspect in this context is the improvement of the economy of reinforced concrete without reducing the safety requirements.

The use of micro alloying is logically linked with high yield strength. This tendency joins the trend towards higher resistance in concrete.

It is very difficult to give a simple figure for the increase in economy caused by a certain increase in yield strength.

The reason is that all constructions are different.

Some years ago in Germany we switched over from grade 420 to grade 500. There for I am able to give you some realistic and well experiences date of this transition. It was in 1985 when we started a new product standard. It exists till now and contains – as already mentioned – grade 420 and 500. Economically thinking people checked the advantages and disadvantages and I was charged to perform an investigation.

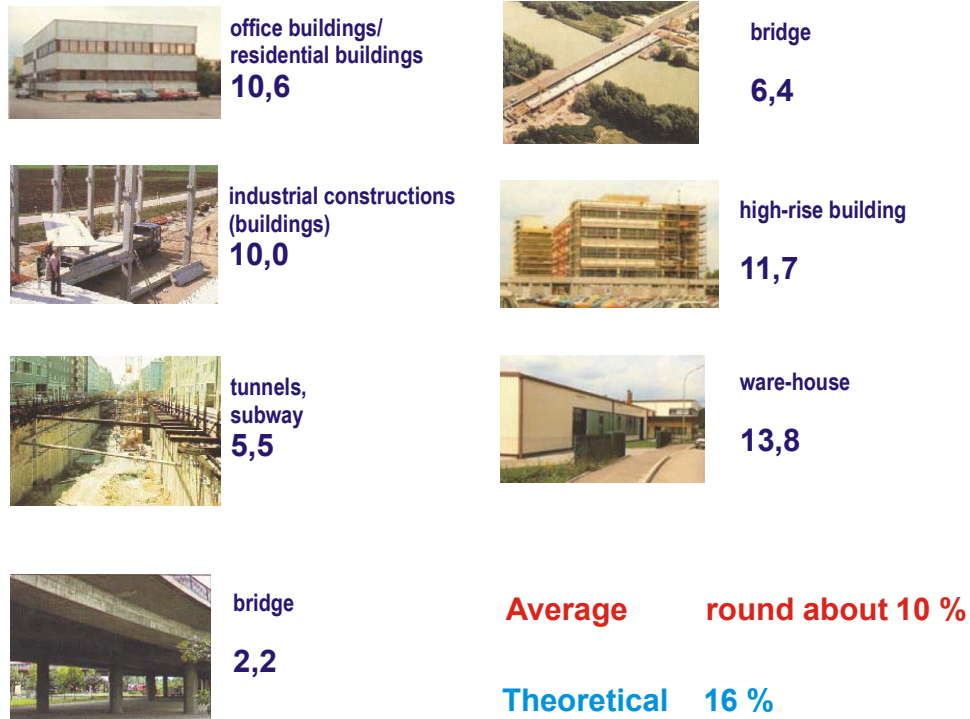
The result from those days – which are still valuable – I will show you.

Theoretically the increase from 420 to 500 means an improvement of round about 16%. Due to the fact that in the different constructions different design rules are dominating. For that reasons I subdivided the constructions into six groups

- office buildings / residential buildings
- industrial constructions (buildings)
- tunnels, subways
- bridges of all sizes
- high-rise buildings
- ware houses

It was possible to compare the amount of reinforcement for this six groups.

Average values for the savings were as shown in Fig. 7.



It means that approximately two third of the theoretical expected saving can be realized. The basis for this considerations are the design codes which are in use till now in Germany.

Additional savings are linked with this reduction of the masses of reinforcement:

- better constructions: more space for concrete
- lower costs for manufacturing reinforcement: less bending, cutting, transport
- faster execution of works

The upper limit for the yield in reinforced concrete depends on different parameters. Taking into account European design codes a yield strength between 480 and 550 fits best.

How the change from a grade 420 to a grade 520 affects the design of a column is shown in Fig. 8.

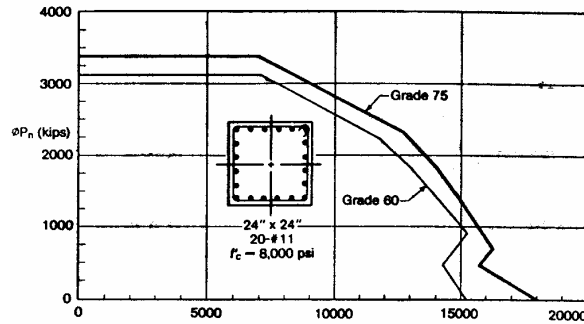


Fig. 8. Load-Moment Graph Showing Savings in Reinforcement

This figure shows indirectly the savings in reinforcement by means of a load-moment interaction graph.

Another very important feature of increasing yield is given by environmental considerations.

The consumption of energy, waste of water amount of alloys and air pollution and output of CO₂ is almost independent whether a grade 400 or 500 is produced!

This aspect gains more and more significance.

Ecological Aspects

The advantage of using high yield strength reinforcement has been pointed out. Increasing the yield and consequently the design values a lower energy consumption and pollution output is evident per used ton of steel.

If a production route on the basis of EAF is chosen quite a series of ecological advantages can be obtained:

- the use of scrap saves iron or
- the melting process demands less energy in comparison with ore-reduction
- some residual elements in steel scrap can be used, as Mn.

How progressive the EAF route concerning inputs, outputs and energy is can be documented by an investigation executed of 7 European steel mills (Fig. 9).

Life Cycle Inventory Data for Steel Products



INTERNATIONAL
IRON AND
STEEL
INSTITUTE

Product : Rebar-Wire Rod-Eng. Steel,
EAF Route,
Europe Average, 1 kg

Date of issue : June 1999

Date of data : 1994-1995

This sheet is supplied for an agreed purpose following consultation with an LCA manager from an IISI member organisation. The table shows IISI LCI data in simplified form. In simplifying such a complex subject there is always a risk that information can be misinterpreted. To avoid any such misinterpretation, these data should not be disclosed to third parties.

Person providing this data sheet:

Name:
Company:

Person receiving this data sheet:

Name:
Company:
Date:

	Major Articles*	Units	Average 7 sites	Min	Max	St. Dev.** Average
Inputs:	(r) Coal	kg	0.0741	0.0194	0.1929	0.82
	(r) Dolomite (CaCO3.MgCO3)	kg	5.52E-05	0.00E+00	3.87E-04	2.45
	(r) Iron (Fe, ore)	kg	0.0068	-0.0823	0.1124	
	(r) Limestone (CaCO3)	kg	0.0762	0.0563	0.0966	0.21
	(r) Natural Gas	kg	0.0550	0.0045	0.1343	0.89
	(r) Oil	kg	0.0271	0.0139	0.0522	0.53
	(r) Zinc (Zn, ore)	kg	-4.13E-03	-6.30E-03	0.00E+00	0.64
	Ferrous Scraps (net)	kg	1.083	1.002	1.156	0.06
	Fresh Water (total)	litre	8.55	0.68	50.06	1.98
	Outputs:	(a) Carbon Dioxide (CO2, fossil and mineral)	g	473	153	1078
(a) Carbon Monoxide (CO)		g	2.98	2.03	5.47	0.36
(a) Nitrogen Oxides (NOx as NO2)		g	1.49	0.53	3.62	0.74
(a) Particulates (total)		g	0.206	0.081	0.598	0.80
(a) Sulphur Oxides (SOx as SO2)		g	1.46	0.39	4.63	0.95
(w) Ammonia (NH4+, NH3, as N)		g	-2.16E-03	-1.54E-02	1.26E-03	
(w) Chlorides (Cl-)		g	0.258	0.019	0.670	0.81
(w) Chromium (Cr III, Cr VI)		g	3.17E-05	-3.14E-06	1.34E-04	
(w) COD (Chemical Oxygen Demand)		g	0.0272	-0.0967	0.1971	
(w) Cyanides (CN-)		g	1.16E-06	0.00E+00	4.97E-06	1.63
(w) Fluorides (F-)		g	0.0125	0.0065	0.0155	0.28
(w) Iron (Fe++, Fe3+)		g	1.62E-03	-2.31E-04	5.51E-03	
(w) Lead (Pb++, Pb4+)		g	9.83E-05	-3.93E-05	5.63E-04	
(w) Nickel (Ni++, Ni3+)		g	7.08E-05	1.49E-05	2.12E-04	0.90
(w) Nitrogen (total except ammonia, as N)		g	-3.19E-03	-1.28E-02	1.45E-04	
(w) Phenol (C6H6O)		g	4.11E-06	1.52E-06	1.35E-05	0.95
(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)		g	9.72E-03	3.27E-04	1.52E-02	0.61
(w) Phosphorus (total except phosphates, as P)		g	0.0777	-0.0024	0.1175	
(w) Sulphides (S--)		g	9.49E-04	-4.79E-03	8.10E-03	
(w) Suspended Matter (unspecified)		g	0.0326	0.0036	0.1118	1.05
(w) Water	litre	6.74	0.25	40.12	2.03	
(w) Zinc (Zn++)	g	6.82E-05	-2.11E-04	7.43E-04		
Non Allocated By-products (total)	kg	0.113	0.013	0.163	0.44	
Waste (total)	kg	0.0633	0.0242	0.1167	0.44	
Energy Reminders:	Total Primary Energy	MJ	11.1	5.0	16.4	0.33
	Non Renewable Energy	MJ	10.0	1.7	16.3	0.46
	Renewable Energy	MJ	1.08	0.15	3.35	0.95
	Fuel Energy	MJ	10.6	4.9	15.4	0.32
	Feedstock Energy	MJ	0.50	0.19	1.05	0.62

* (r): Raw material in ground, (a): Airborne emissions, (w): Waterborne emissions

** A full listing of IISI LCI data contains 450 articles, only major articles are shown here.

** Not suitable for values with negative and positive ranges.

Summary

Reinforcing steel is a quantitative outstanding steel product.

Due to its use as reinforcement in the compound system reinforced concrete it has to provide a large number of performance characteristics. Among them yield strength, ductility, weldability, bendability, workability, fatigue and other are of main importance and depend directly upon the metallurgy of the steel.

Therefore the production route plays an important role. Moreover the characteristics are mutually depending and it is wise to elaborate an optimisation.

This optimisation can successfully be reached in applying the micro alloying process on the basis of nitrided vanadium alloy.

This statement is correct for both steel making processes electric furnace and converter.

The technology is well proven and simple in its application. No main changes in the equipment are necessary as well as additional cost effective investment.

Due to the perfect homogeneity of precipitations and grain size a high quality level can be reached which is of highest importance for the construction industry.

For economic reasons higher yield strength should be intended: This brings benefits to the building industry and is technically without any risk because even with high yield strength no decrease in the other important properties is given.

There are some fields where micro-alloyed reinforcing steel is unbeatable. On the other hand I recommend the researchers to extend their activities to some new sectors as

- corrosion protection in concrete
- high ductile straightened wires.

