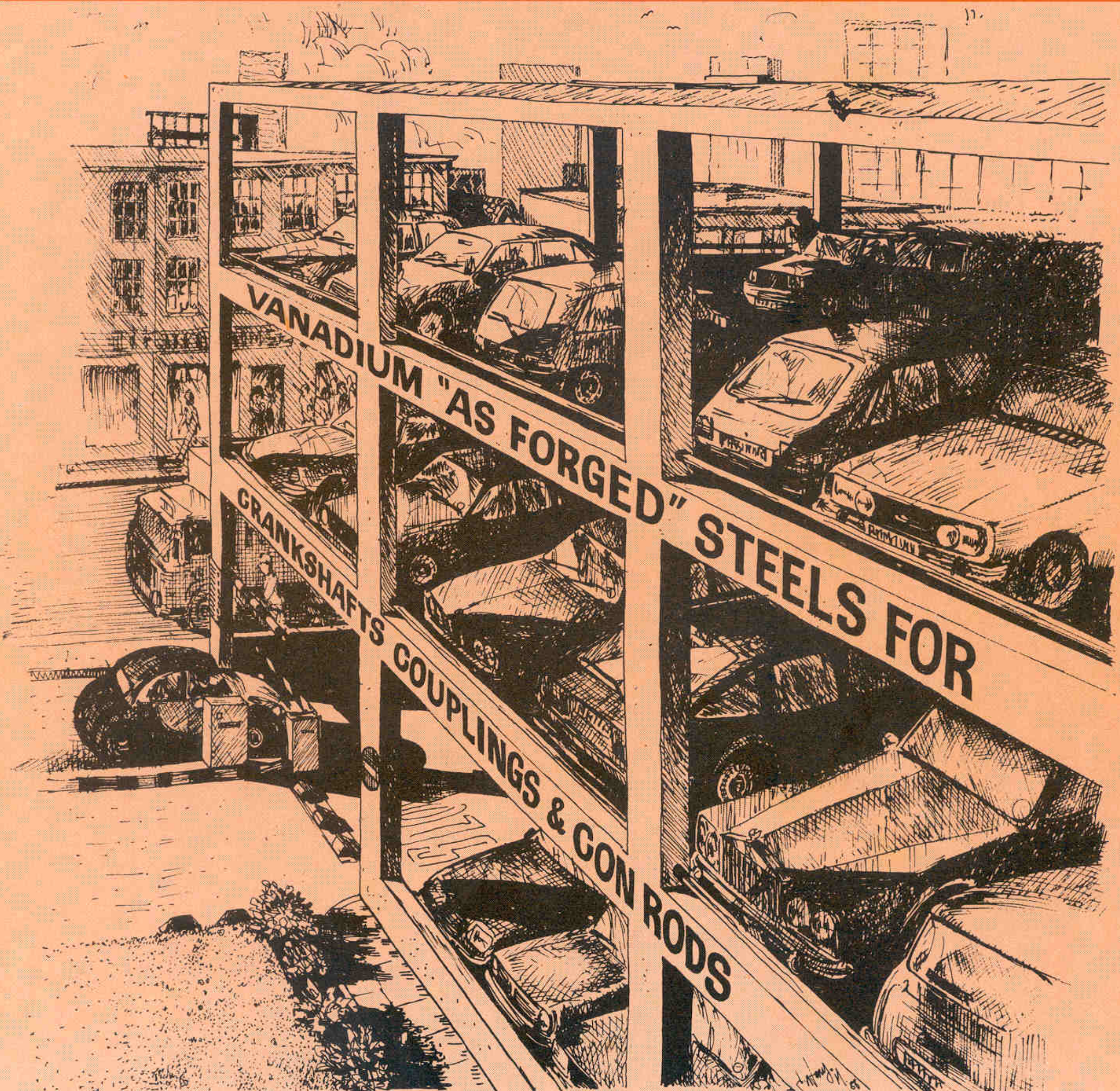
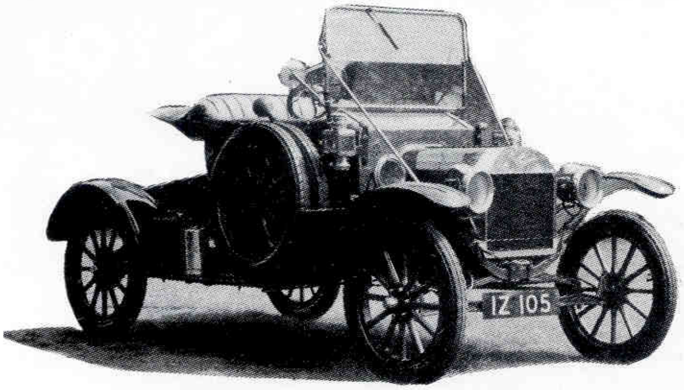
VANADIUM "AS FORGED" STEELS for Automobile Components

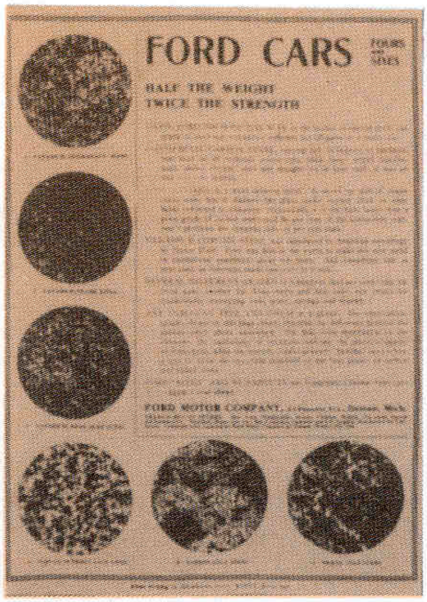


VANITEC

Monograph No 3

VANADIUM STEELS AT THE OPENING AND ...





"Several different grades of vanadium steel are used - one for front axles ... others for crank-shafts, connecting rods, gears, springs and frames...

The fine even distribution of the elements - the uniformity of structure indicate the superior quality of vanadium."

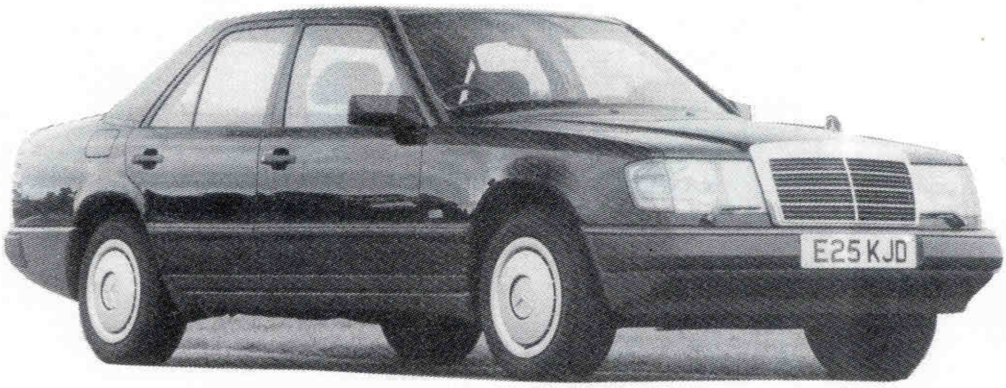
Henry Ford, 1910.

Vanadium steels were used for many engine parts in automobiles made at the beginning of this century including the famous Model "T" Ford. Advertisements for Ford cars in fact attributed their superior performance to the use of fine grained vanadium steels.

When heat treatment furnaces with improved temperature control were developed in the 1920's quenched and tempered carbon steels and later alloy steels were adopted for these components. Today, however, fuel and labour costs have increased so that steels with vanadium additions which can be used in the "as forged"condition are once again the lowest cost materials. As a result vanadium "as forged" steels have steadily replaced the heat treated steels for crankshafts, steering knuckles, front axles and other components.

Recent developments in manufacturing techniques and in alloy steel development enabled the modern vanadium "as forged" steels to be made with considerably increased strength, fatigue resistance and improved machinability and with greater uniformity of these properties to meet the increasingly severe demands of the automobile engineers.

Many of the leading motor manufacturers including Mercedes, Volvo, British Leyland, Volkswagon, Mitsubishi and Toyota cars use Vanadium "as forged" steels for a number of components in many of their models.



Photograph by courtesy of Daimler Benz.

...AT THE CLOSE OF THE 20TH CENTURY

VANADIUM FORGED STEELS...

- Require no special forging techniques or practices.
- Do not require heat treatment.
- Do not distort during processing
- Do not require straightening.
- Are almost free from internal stresses.
- Are amenable to high production practices.
- Are easy to machine and can reduce machining costs.
- Can be supplied to high dimensional tolerances.
- Have a high strength
- Have greater uniformity of properties
- Have high fatigue resistance.
- Reduce tool wear.
- Have lower initial steel cost than heat treated alloy steels.
- Can be pressed or hammer forged without special practices.
- Increase productivity.
- Reduce rejects.
- Reduce inventories and financing costs.
- Can be induction hardened.
- Can be nitrided without distortion.

VANADIUM "AS FORGED" STEELS

AVOID COSTS OF...

... Heat Treatment.

When forgings are produced from "as forged" Vanadium steels the heat treatment processes are unnecessary and savings result from:-

- Fuel for heating heat treatment and tempering furnaces
- Refractories
- Maintenance of burners and handling equipment
- Operation and maintenance of instrumentation
- Labour
- Amortisation costs for furnaces and buildings

Straightening.

When forgings are made with "as forged" Vanadium steels distortion arising from the heat treatment does not occur and consequently the straightening operations become unnecessary so that the costs for operating the straightening presses are avoided.

REDUCE COSTS OF...

... Handling

When Vanadium "as forged" steels are used the forgings are taken directly from the forge hammer or press to the machine shop thus avoiding the costs of transporting them to the heat treatment shop, and within the heat treatment shop.

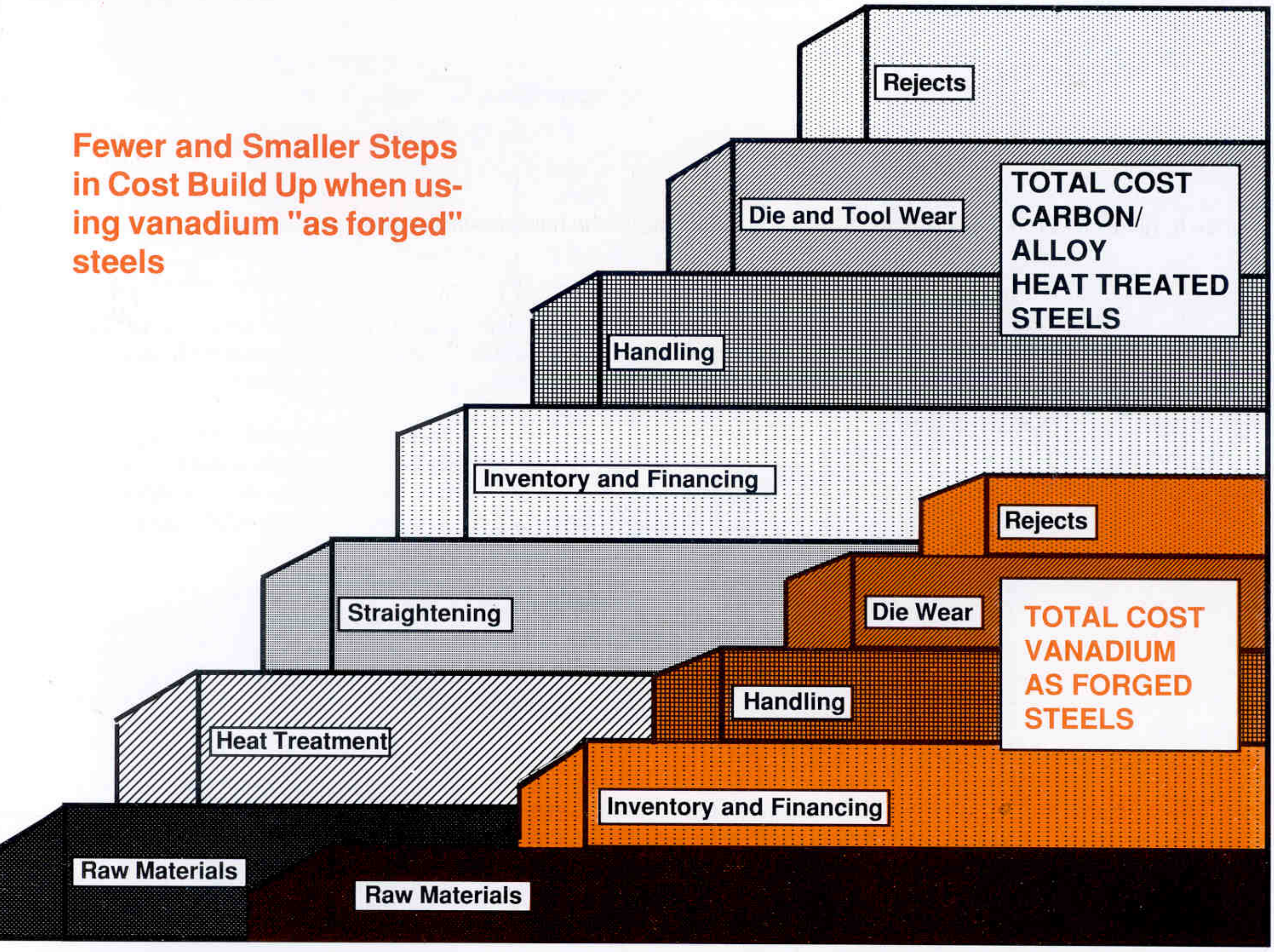
... Inventory and Financing

When forgings are made from "as forged" Vanadium steels they go directly from the forge to the machine shop and do not have to be stored awaiting heat treatment, tempering and straightening. The "in track " time therefore is shorter and inventories are lower and thus financing costs are reduced.

... Raw Material

Although many heat treated components are made from carbon steels, the heavier forgings and those made to high tensile grades required alloy additions including molybdenum or chromium. The cost of the small amount of vanadium added to the "as Forged" steels is much lower than the cost of molybdenum and chromium additions so that the alloy costs are reduced.

Fewer and Smaller Steps in Cost Build Up when using vanadium "as forged" steels



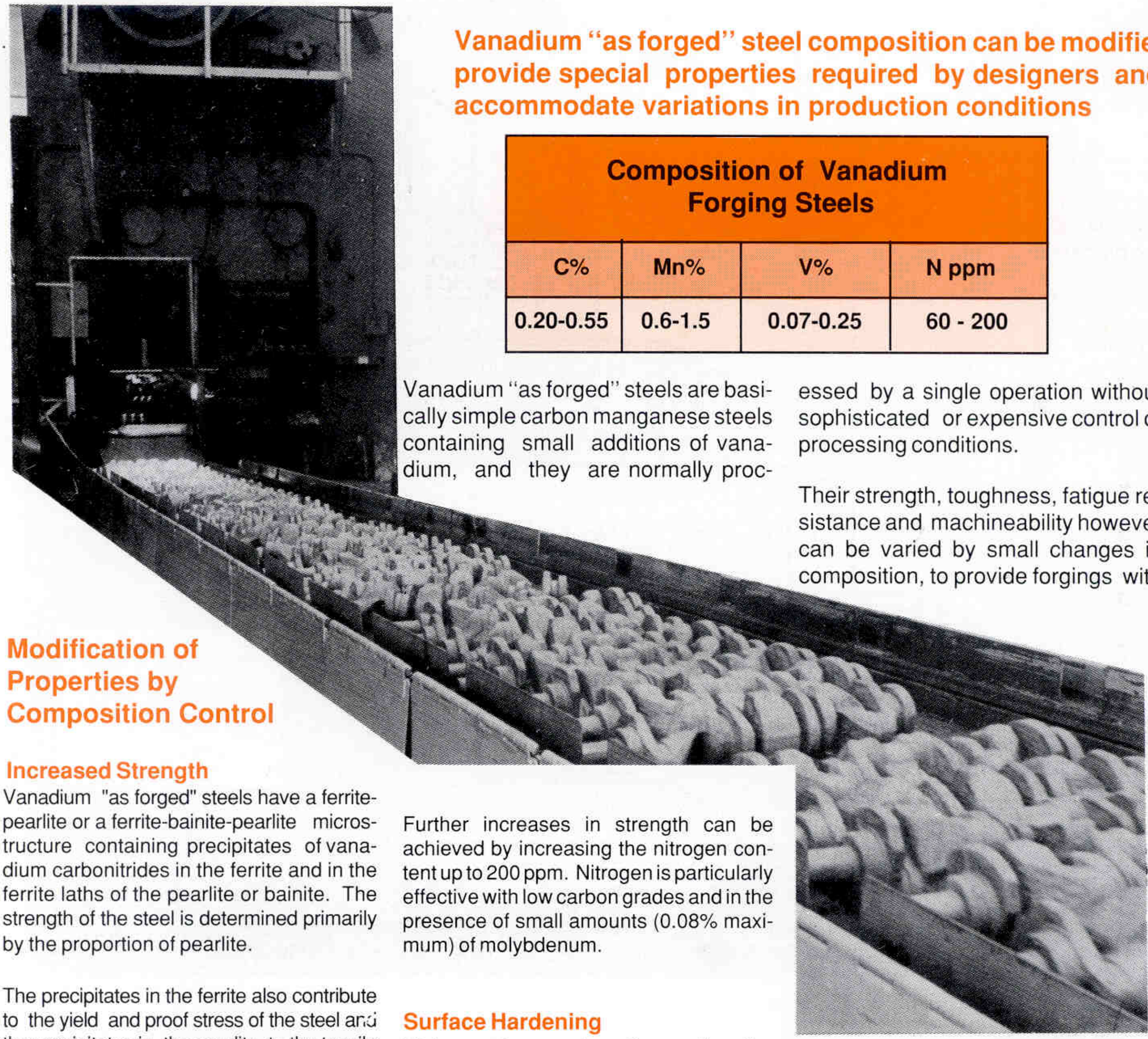
... Tools and Dies.

The addition of vanadium to steels unlike the addition of molybdenum or chromium does not affect the strength of the steel at the forging temperatures so that die wear is less. When using vanadium steels, therefore, die life is longer so that die costs are lower and production costs are also reduced because die changes and consequent interuptions in production are less.

... Rejects.

By removing the heat treatment and straightening operations there is no possibility for irregularities in these processes giving rise to scrap and costs arising from material rejected fron these operations do not arise when using "as forged" vanadium steels..

--- CRANKSHAFTS and other Components for



Vanadium "as forged" steel composition can be modified to provide special properties required by designers and to accommodate variations in production conditions

Composition of Vanadium Forging Steels			
C%	Mn%	V%	N ppm
0.20-0.55	0.6-1.5	0.07-0.25	60 - 200

Vanadium "as forged" steels are basically simple carbon manganese steels containing small additions of vanadium, and they are normally processed by a single operation without sophisticated or expensive control of processing conditions.

Their strength, toughness, fatigue resistance and machineability however can be varied by small changes in composition, to provide forgings with

Modification of Properties by Composition Control

Increased Strength

Vanadium "as forged" steels have a ferrite-pearlite or a ferrite-bainite-pearlite microstructure containing precipitates of vanadium carbonitrides in the ferrite and in the ferrite laths of the pearlite or bainite. The strength of the steel is determined primarily by the proportion of pearlite.

The precipitates in the ferrite also contribute to the yield and proof stress of the steel and the precipitates in the pearlite to the tensile strength. Forgings with tensile strengths up to 1100 N/mm² (160 k.s.i.) are possible when vanadium additions are made.

Further increases in strength can be achieved by increasing the nitrogen content up to 200 ppm. Nitrogen is particularly effective with low carbon grades and in the presence of small amounts (0.08% maximum) of molybdenum.

Surface Hardening

Higher carbon grades of vanadium "as forged" steel can be surface hardened by induction heating. All grades can be hardened by nitriding.

Heavy Sections

Steels made to the higher strength grades and for heavier forgings have higher carbon contents to increase the volume fraction of pearlite and larger percentages of vanadium to increase the volume fraction of precipitates.

Typical compositions of vanadium "As forged" steels supplied for forgings having ruling sections up to 100 mm.

Chemical composition

Ruling section	C	Si	Mn	P	S	V
<25 mm	0.42/0.47	0.15/0.35	1.20/1.50	0.035max	0.05max	0.08/0.13
>100 mm	0.45/0.50	0.15/0.35	1.20/1.50	0.035max	0.05max	0.10/0.15

Tensile Properties

U.T.S. N/mm²	P.S. N/mm²	Elong %	Charpy-V Joules	Hardness BHN
930/1080	625 min	10 min	10 min	269/331

Toughness

Low carbon and high manganese contents (with appropriate increases in vanadium content to maintain strength) can be used to increase the shelf energy in components when this is important

This can also be increased by refinement of grain size and pearlite colony size or by addition of titanium or aluminium to refine the ferrite grain size.

Chromium may also be added to create a bainitic structure to improve toughness at low temperatures.

Machinability

Chromium may be added as a partial substitute for manganese, especially in ingot casting practice, to reduce the colony size of pearlite and to refine the interlamellar spacing of the pearlite thus improving machinability.

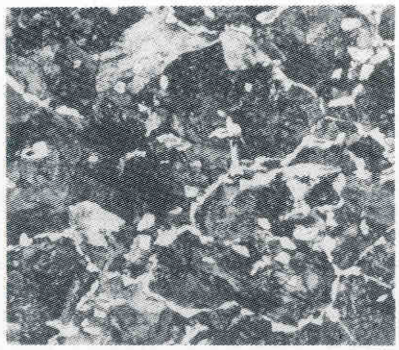
AUTOMOBILES and TRUCKS

the different combinations of properties required in various components with varying cross section thickness and to take account of special design characteristics.

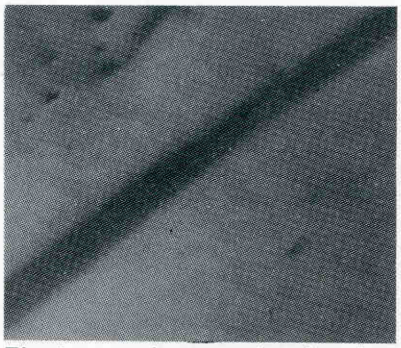
In some plants special properties can also be achieved by simple variations in processing, notably the cooling rate after forging.

The different processing routes found in production plants including B.O.F. electric arc steel, continuous casting or ingot casting, hammer forging or press forging, can influence the microstructure and properties. The effects of all of these parameters can be accommodated by small changes to the basic simple carbon manganese vanadium steel composition.

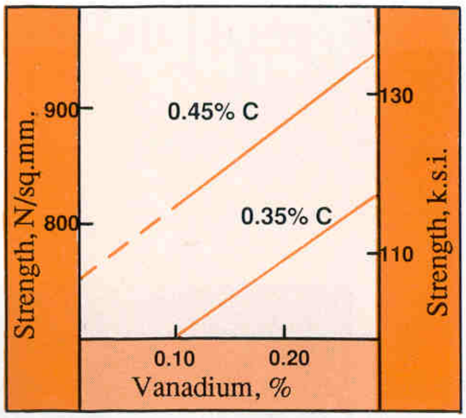
Small changes in composition can also be made to ensure maximum effectiveness of induction hardening and nitriding and to achieve maximum effectiveness and good surface finish in all types of machining operations with carbide tipped tools or high speed steels.



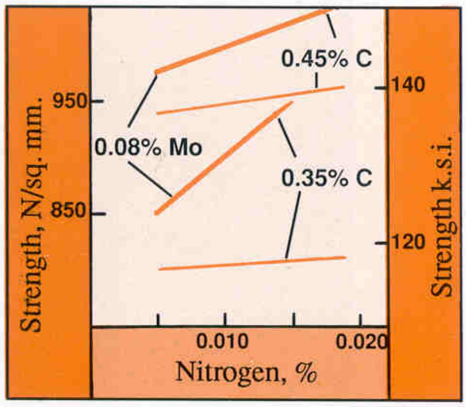
Ferrite pearlite microstructure of Vanadium "As forged" steel Crankshaft



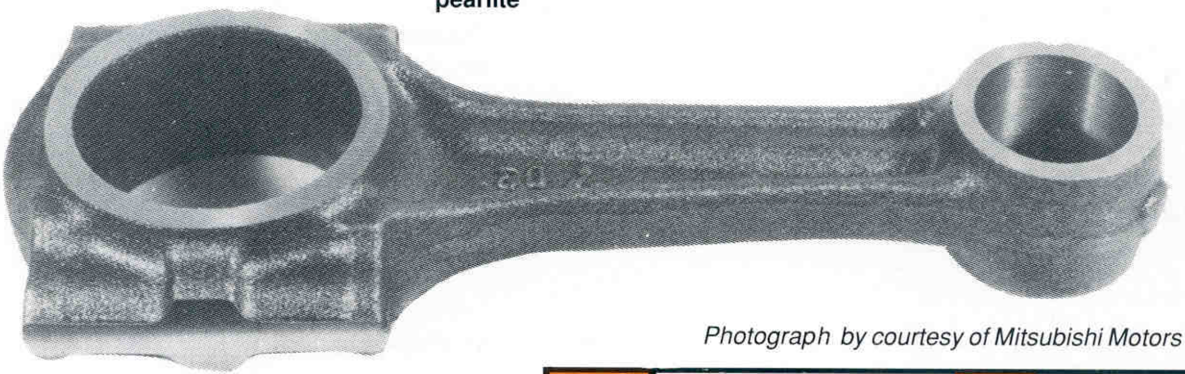
Electron micrograph showing strengthening precipitates of Vanadium Carbonitride in ferrite laths of pearlite



The effect of vanadium on tensile strength of forgings



The effect of nitrogen on tensile strength of forgings

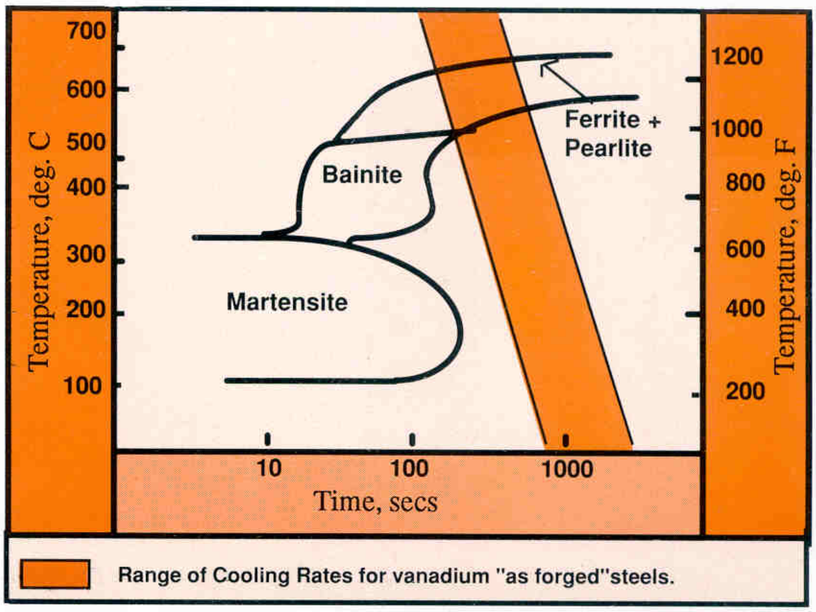


Photograph by courtesy of Mitsubishi Motors Corporation.

Automotive connecting rod

Effect of Cooling Rate

Vanadium steel forgings are normally cooled in air without any special control of cooling except to avoid very slow cooling rates as can occur by cooling them in bins. Some additional strength however can be achieved if they are cooled in an air draft. This refines the pearlite colony size and refines the vanadium precipitates.



CCT Diagram for 0.45%Carbon Manganese Vanadium forging steel

VANADIUM "AS FORGED" STEELS can be

HAMMER FORGED or HOT PRESSED

Photograph by courtesy of United Engineeringand Forging

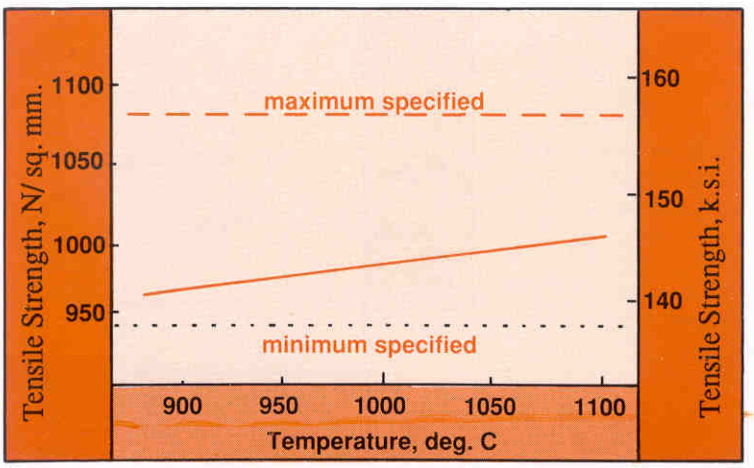
Vanadium steels are easy to forge because they only contain small additions of alloy which do not harden the steel or increase its resistance to deformation at forging temperatures. Vanadium steels can be forged by hammers or in presses.

Reheating temperatures are in the range 1180°C to 1300°C (2156°F to 2372°F) and at these temperatures all vanadium carbonitrides which provide strength from precipitates forming at lower temperatures are in solution even when the steels are rapidly heated by induction methods. The forging operation is usually completed before the steel cools to 900°C (1652°F) and no precipitation of vanadium carbonitrides and consequent hardening of the steel therefore occurs throughout the forging operation.

Any tendency for the formation of bainite which can embrittle the steel through fast cooling of small forgings made under hammer presses can be avoided by small additions of titanium which refines the austenitic grain size of the steel and therefore decreases its hardenability.

Reduced Die Wear

Vanadium steels because they do not usually contain alloys or precipitates which harden them at forging temperatures cause less wear on dies which consequently last longer. This increases productivity and reduces costs.



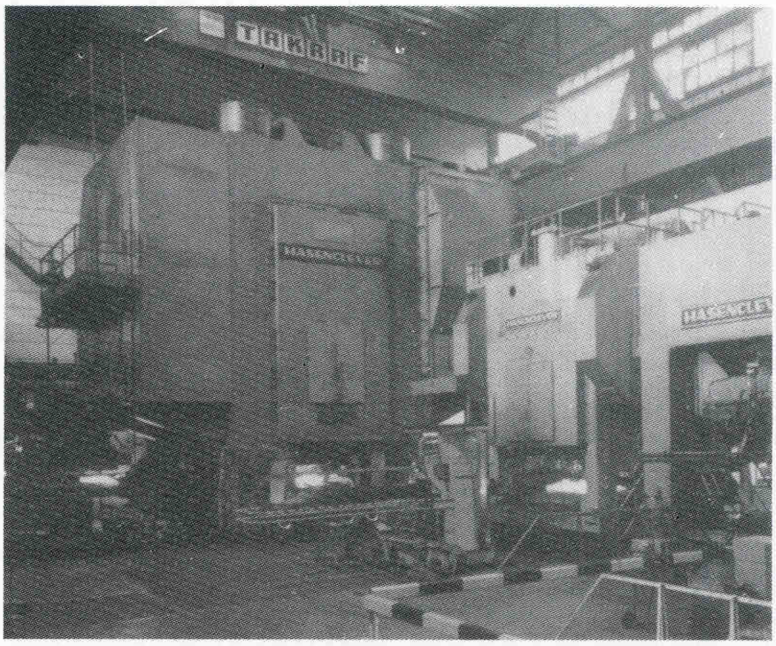
Effect of forging temperature on Tensile strength

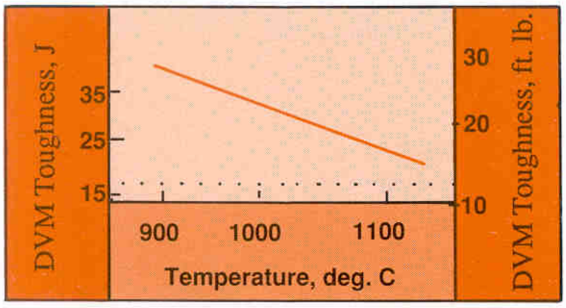
Improved Properties by Control of Forging Conditions

Most Vanadium steel forgings are cooled without any specific control of cooling conditions, although it is important that in order to ensure that the vanadium carbonitrides are of an effective size that the forgings are not cooled too slowly. It is therefore common practice in forges making vanadium steels to place the forgings on a conveyor on which they cool in air at a satisfactory rate. Cooling in bins at least while the forgings are at a temperature above 600°C (1112°F) is to be avoided.

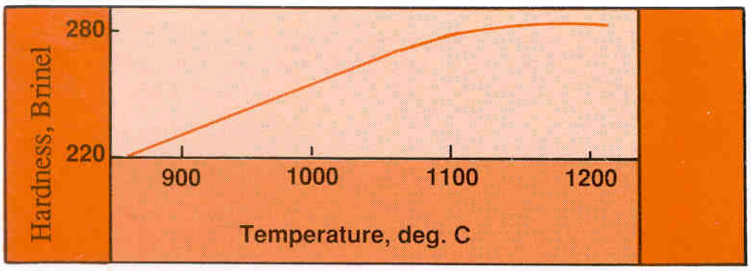
Increased Strength by Control of Cooling Rate

Where forgings of increased strength and toughness are required the forgings may be given some accelerated cooling after forging to refine the grain size and the precipitate size. This treatment may also be applied to increase the ruling section of forgings which can be made to a given strength specification and to increase the uniformity of the product. Increased cooling rate can be achieved by a simple air draft created by fans mounted under the conveyor on which the forgings are transported from the forging press or hammer.





Effect of forging temperature on toughness



Effect of forging temperature on hardness

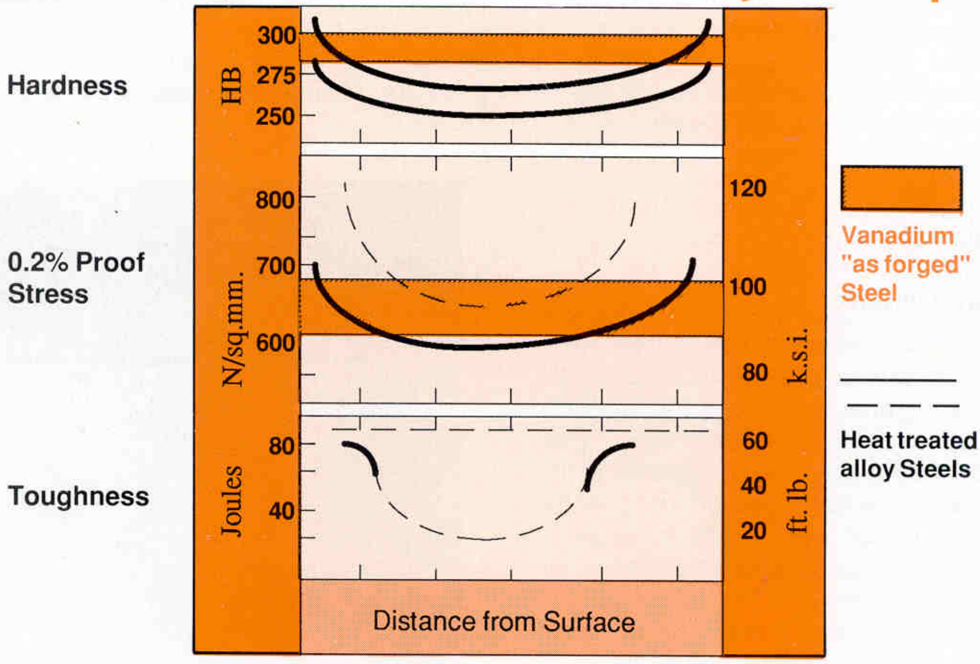
Increased Strength by Control of Forging Temperature

The finishing forging temperature can influence the properties of forgings to a small degree and control of this temperature can be used to improve the strength of forgings although some loss in toughness may also result.

Decreasing the finish forging temperature can mean that forging is completed at a temperature below which recrystallisation takes place. This leads to a finer austenite grain size and a lower transformation temperature and finer ferrite grain size and finer precipitate size. Thus higher strength and hardness are attained.

VANADIUM "AS FORGED" STEELS HAVE ...
...Through Thickness Uniformity of Properties

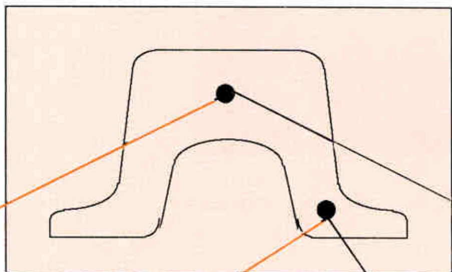
Vanadium "as forged" steels have greater uniformity of properties than heat treated steels



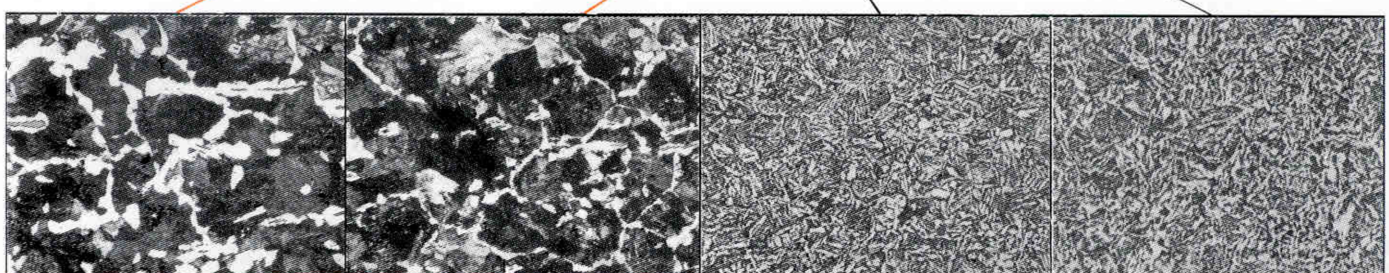
Vanadium "as forged" steels, have a uniform microstructure from the surface to the centre of the forgings and therefore exhibit uniform strength and other properties from the centre to the outside. Heat treated steels on the other hand which have a tempered martensite structure can show a marked increase in coarseness of this structure in the centre which can give rise to significant differences in strength and other properties between the centre and the outside of the forging. In order to achieve adequate consistency of properties in such forgings, the carbon content is relatively high and additions of expensive alloying elements including chromium, molybdenum and nickel have to be made to increase the hardenability. Such alloy additions are unnecessary with the vanadium steels.

The uniformity of structure and properties obtainable in vanadium steels, enables forgings with ruling sections of up to 100 mm to be made with guaranteed minimum properties in the centre.

Comparison of properties in the centre of thick and thin portions of a coupling made in "as forged" vanadium steel and in a heat treated carbon steel



Photomicrographs by courtesy of B.S.C., Swinden Laboratories



270 h.b.	271 h.b.	253 h.b.	241 h.b.
Ferrite Pearlite structure of **"As forged" Vanadium steel**		Tempered Martensite structure of **Heat treated Carbon Steel**	

...Dimensional Accuracy, Stability and Good Surface Finish

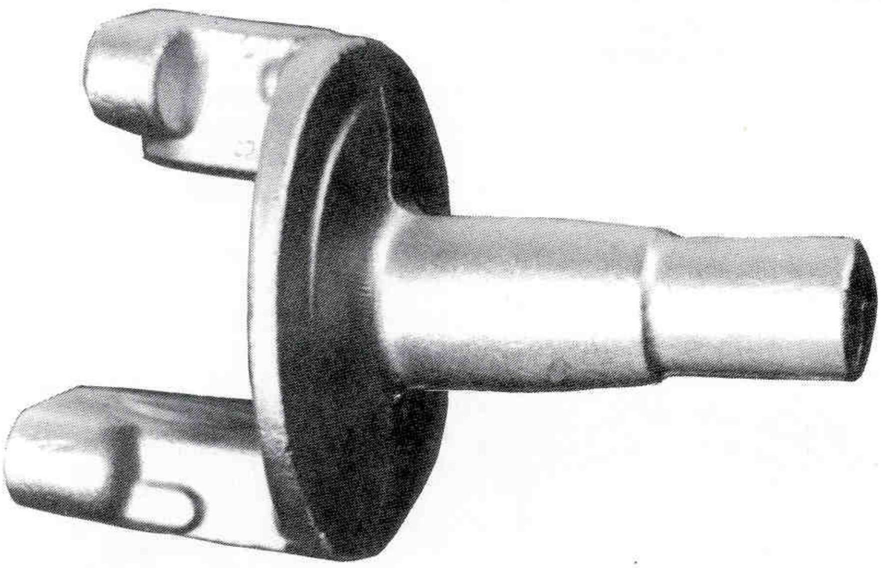
Vanadium "as forged" steels are not subject to the distortion which can arise when heat treated steels are quenched in water or oil from about 850°C (1562°F). Such treatment can not only give rise to distortion in the as quenched component, but can cause internal stresses which can give rise to distortion when these are relieved during machining operations.

The fact that vanadium steels are supplied in "as forged" condition, also means that they are not subject to surface scaling which can take place during heat treatment, and which can lead to expensive descaling operations and loss of dimensions to which heat treated components are prone.

The distortion of heat treated components is corrected by straightening operations, which themselves can introduce further internal stresses. When using "as forged" vanadium steels however, the cost of the straightening operation and the hazard of internal stresses are avoided.

Photograph by courtesy of Daimler Benz.

Connecting rods in engine of Mercedes truck made from "as forged" vanadium steel



Photograph by courtesy of AB Volvo.

Stub axle.

HIGH SULPHUR FOR HIGH GRADE SURFACE FINISH

Exceptionally high grade surface finishes can be produced in "as forged" vanadium steels, as with carbon and low alloy steels, by increasing the sulphur content of the steel to about 0.1%. This decreases the feed forces on the tool, reduces chip length and the temperature of the steel during machining. All of these factors contribute to high quality surface finish.

--VANADIUM "AS FORGED" STEELS can be

Many forgings in automobiles especially those operating at engine temperatures, do not need to have high toughness and indeed under some conditions castings, which have considerably lower toughness than forgings, can be used. "as forged" materials however have a ferrite-pearlite microstructure, and are not usually as tough as heat treated forgings which have a tempered martensite structure. For applications where engineers require maximum toughness at temperatures above about 0°C, i.e. above the brittle transition temperature where the pearlite content in the microstructure is kept to a minimum and every attempt is made to keep the pearlite colony size and the inter-laminar spacing as small as possible.

In the case of certain components such as front wheel axles, which can be exposed to low ambient temperatures during service, it is desirable to further increase the toughness of the steel at low temperatures. This can be achieved with a bainitic structure which gives a lower transition temperature but a lower room temperature shelf energy.

Photograph by courtesy of Mitsubishi Motors Corporation

Mitsubishi Canter Truck with front axle made from vanadium bainitic steel

Ferrite pearlite steels with improved toughness

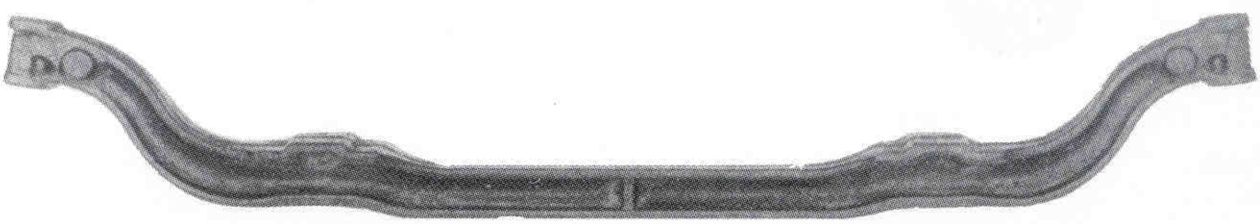
Many forgings such as crankshafts, operate at temperatures above the ductile brittle transition temperature of normal ferrite pearlite carbon steels containing vanadium, and the toughness of such steels is adequate for these components.

Where greater toughness is required, lower carbon contents to reduce the proportion of brittle pearlite in the microstructure and higher manganese contents to lower the

Grain Refinement with Aluminium

Grain refinement can be achieved in forgings which are to be induction hardened by controlled additions of aluminium and increased nitrogen content. Such forgings can be made from ingot or continuously cast steel. The austenite grains are inhibited from growth by aluminium nitride particles which form during the reheating of the steel for forging, and remain out of solution during the short time the steel is at temperature in the induction heating process.

Excessive additions of nitrogen are however to be avoided in steels heated for forging by induction as gross particles of vanadium nitride which can form during heating can reduce the precipitation in ferrite and hence reduce strength.



Photograph by coutesy of Mitsubishi Motors Corporation

Bainitic "as forged"vandium steel front axle of a Mitsubishi Canter Truck

produced with increased toughness

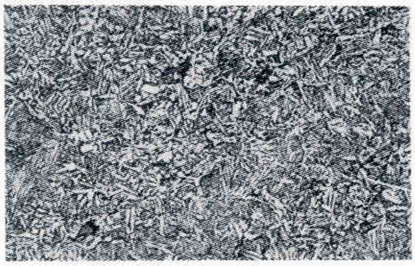
transformation temperature and thus refine the pearlite colony size and interlaminar spacing are employed. The loss in strength resulting from the lower proportion of pearlite, is partly made up by the increase in solid solution strengthening from the higher manganese content. Further solid solution strengthening can be achieved by increasing the silicon content and increased precipitation strengthening can be achieved by increasing the vanadium content.

Grain Refinement with Titanium

Alternatively, grain refinement can be achieved by the addition of 0.01 to 0.02% titanium and increasing the nitrogen content. Titanium forms titanium nitride at a high temperature (while the steel is liquid or immediately after solidification) and the fine particles remain out of solution during rolling of bar and during forging, regardless of the heating process. Titanium treated steels can therefore be used for forgings which are reheated for forging in gas fired or induction heating furnaces. The use of titanium for grain refinement is particularly suited to forgings made from bars rolled from continuously cast billets; or from small ingots.

Toughness at Extra Low Temperatures through Low Carbon Bainitic Microstructures

Where exceptional toughness is required, as for example front wheel axles which can be called upon to operate at very low ambient temperatures, a steel with a predominantly bainitic microstructure can be used to increase the toughness at low temperatures. Such steels contain small additions of chromium which together with the vanadium increases the hardenability so that a ferrite bainite pearlite micrstructure is obtained. The bainite gives a lower transition temperature to the steel than pearlite but a slightly lower shelf energy. A small amount of pearlite is retained in the microstructure to ensure good machineability.

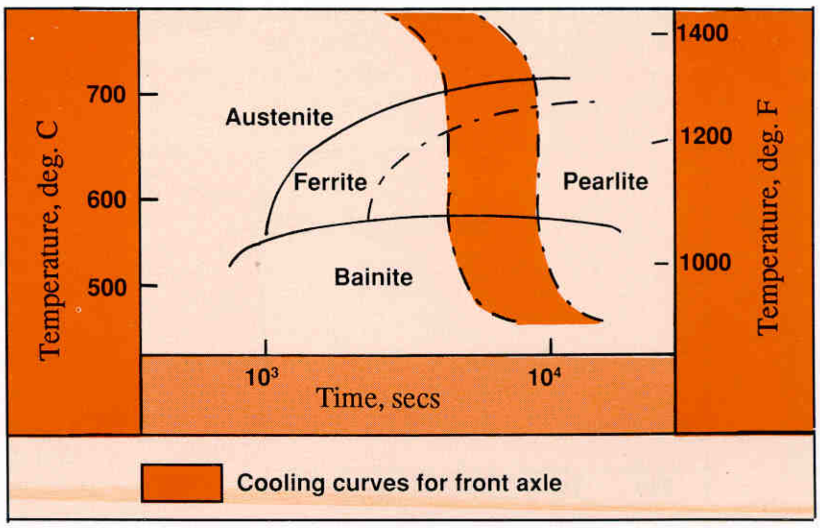


Microstructure of bainite pearlite steel for front axle of Canter truck

Typical Composition and Properties of Ferrite-Bainite-Pearlite Forging Steel for front axles

C	Si	Mn	P	S	Ni	Cr	Mo	Cu	V
0.20	0.34	1.07	0.012	0.05	0.10	0.34	0.04	0.04	0.10

Tensile Strength		Yield Strength		Elong.	Charpy -40°C. 40°F	
N/mm²	k.s.i.	N/mm²	k.s.i.	%	J	ft.lb.
940	136	705	102	22	41	31



C C T Diagram for a bainitic steel forging

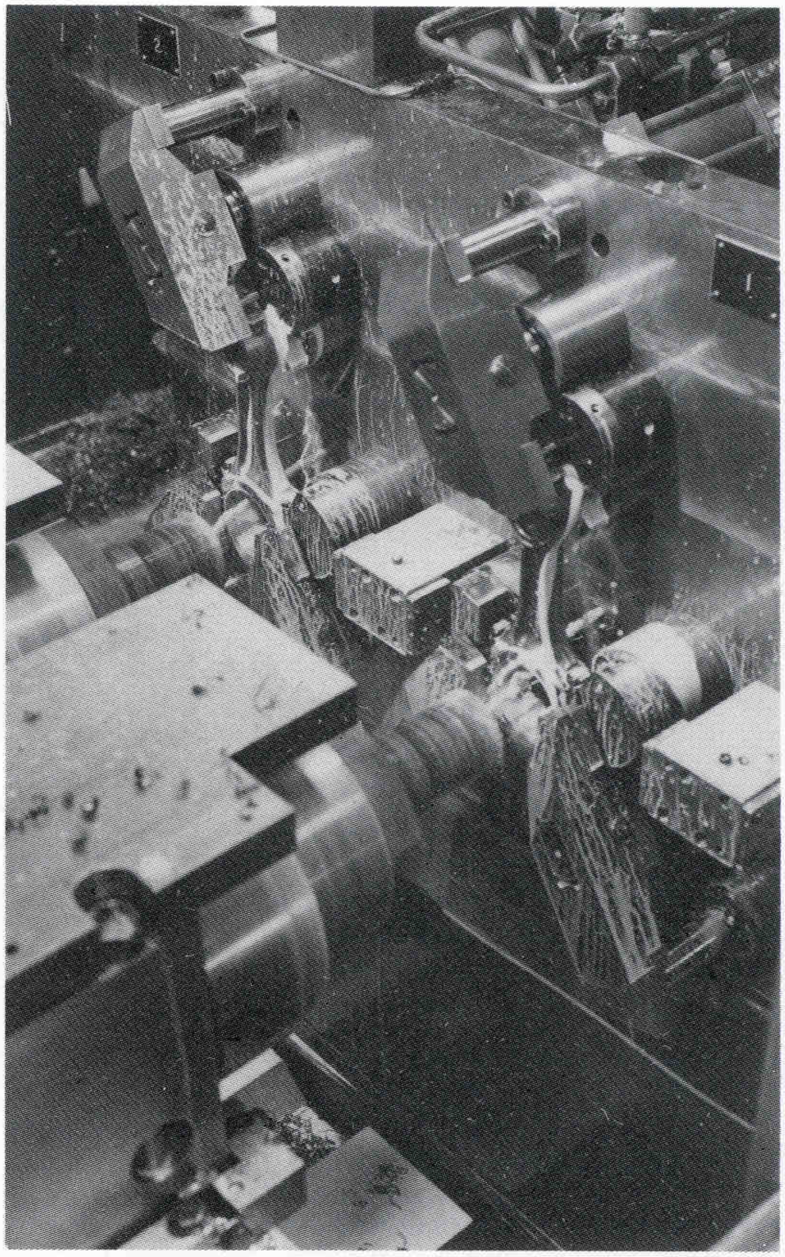
---- VANADIUM "AS FORGED" STEELS HAVE

The machinability of a steel for most automobile components, many of which are machined with high speed tools, is of paramount importance in the selection of a steel .

In some components, such as connecting rods or transmission shafts, the cost of the machining operations when carbon or low alloy steels are used can amount to 57% or 67% of the cost of the forging and when "as forged" vanadium steels are used, this can be significantly higher. It is therefore of the greatest importance that the steel should be at least as machinable as the carbon and low alloy heat treated steels.

The machinability of "as forged" vanadium steels is in fact equal to or superior to that of quenched and tempered carbon and low alloy steels under most conditions of machining whether they are machined with high speed steels or with carbide tipped tools. Further, the steels respond well to additions of sulphur or lead to increase their machinability when when they are machined with high speed steel tools and such additions have no adverse effects on their mechanical properties.

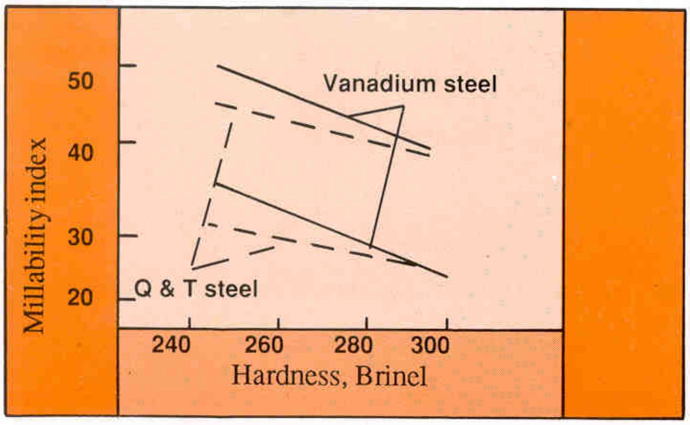
It is of course essential, as with the machining of all steels, that the appropriate tool designs (Rake angle etc.) should be used for each operation to achieve the maximum tool life and minimum tool wear.



Photograph by courtesy of United Engineering and Forging

Milling

The milling of the lower hardness grades of vanadium "as forged" steels is easier than the quenched and tempered steels. Even when machining, the higher hardness grades milling is no more difficult than with the heat treated steels.



Millability of vanadium "as forged"steel

Sulphur treated steels for improved surface and machinability

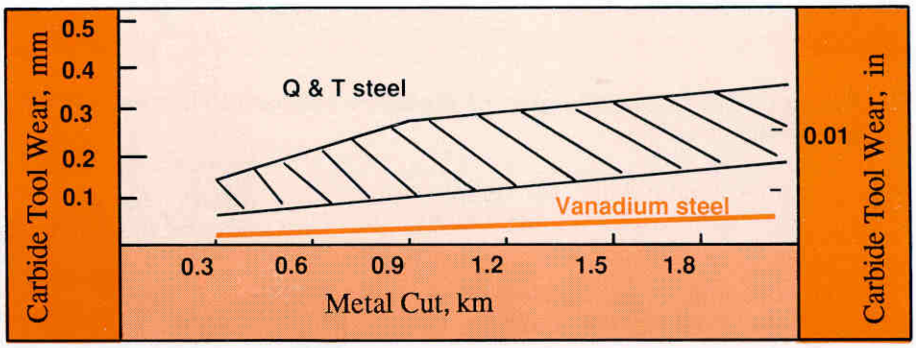
High sulphur contents are used in vanadium "as forged"steel components when a combination of high surface quality and extra machinability are required.

SUPERIOR MACHINABILITY

Turning

The superior machinability of the "as forged" vanadium steels as compared with quenched and tempered carbon steel of similar strength can be demonstrated for both high speed steel and carbide tipped tools.

The machinability of all types of steel decreases with increasing hardness of the forgings but the effect of increased hardness on the life of high speed steel tools is less for "as forged vanadium steels than for heat treated carbon or alloy steels of equivalent hardness and strength.

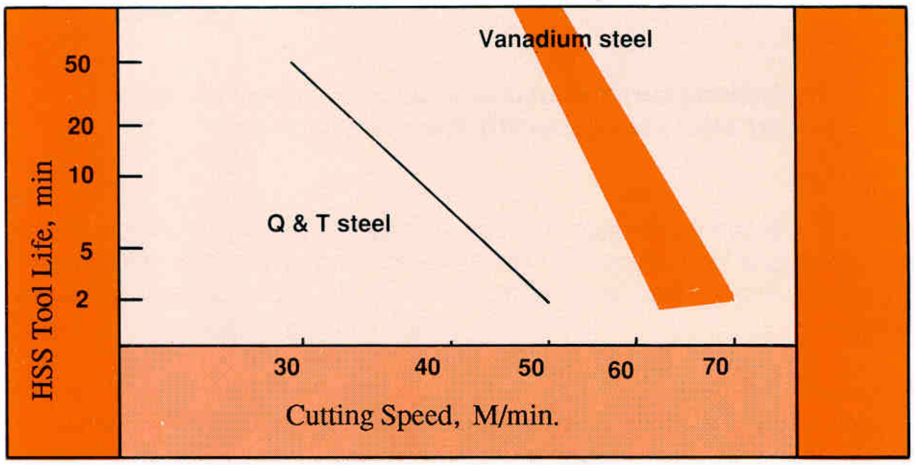


Wear of Carbide Tipped tools when machining "As forged" Vanadium forgings and heat treated forgings

Although the average machinability of vanadium "as forged" steels when machined with high speed steels is about the same as for quenched and tempered steels of the same hardness, the scatter in machinability is less and this leads to greater economies in the machine shop.

The chip length of turnings from vanadium "as forged" steels are about 30% shorter than those coming from quenched and tempered steels and they are therefore easier to control.

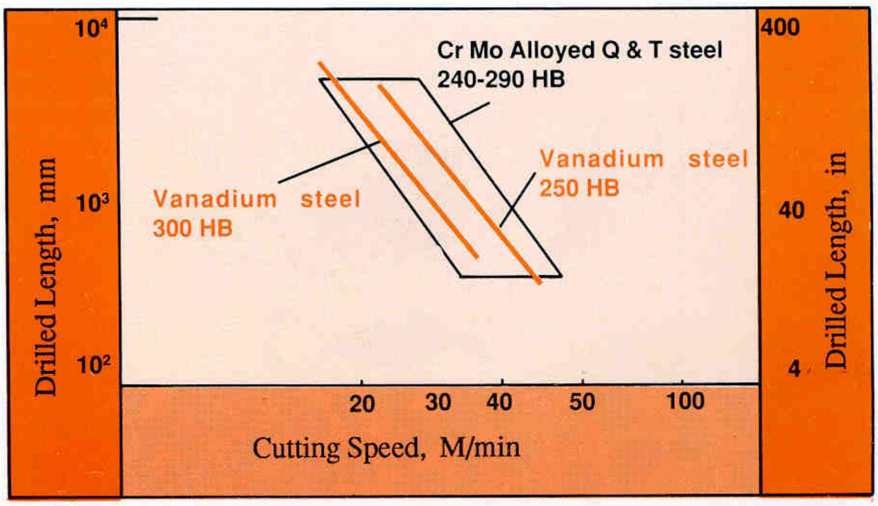
When turning with cemented carbide tools the "as forged" vanadium steels give less tool wear.



High Speed Steel Tool life when machining vanadium Steel forgings

Drilling

The drilling of vanadium "as forged" steels is as easy and convenient as with quenched and tempered steels but it is important to use bits with wide chip removal channels to ensure that the chips, which tend to be more powdery with the vanadium steels, are removed effectively.



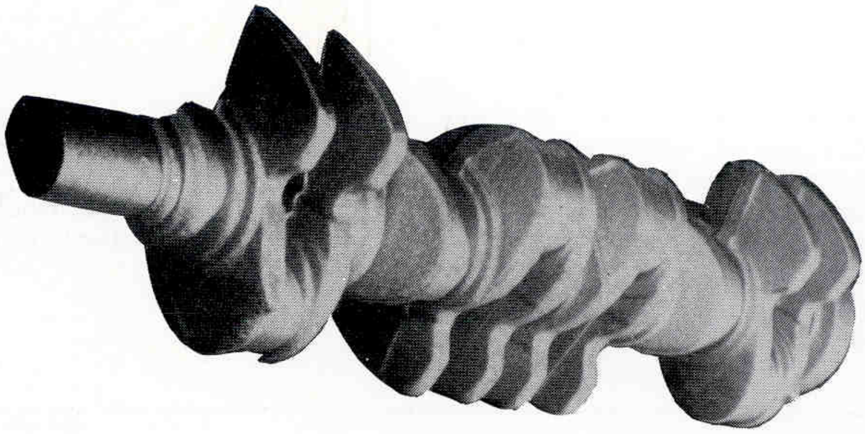
Drillability of vanadium "as forged" steels

VANADIUM STEELS CAN BE SURFACE HARDENED AND WELDED

Forgings are frequently given a surface treatment to increase the hardness wear resistance and fatigue properties.

Induction Hardened Surfaces

Full advantage can be taken of the convenience of induction methods for the surface hardening of components produced on a large scale when using vanadium "as forged" steels. In order to achieve satisfactory hardening however, it is essential that the carbon content be between 0.40 and 0.45% to ensure adequate hardenability.



The bearing surfaces of crankshafts of vanadium "as forged"steels are frequently induction hardened

Nitrided Surfaces

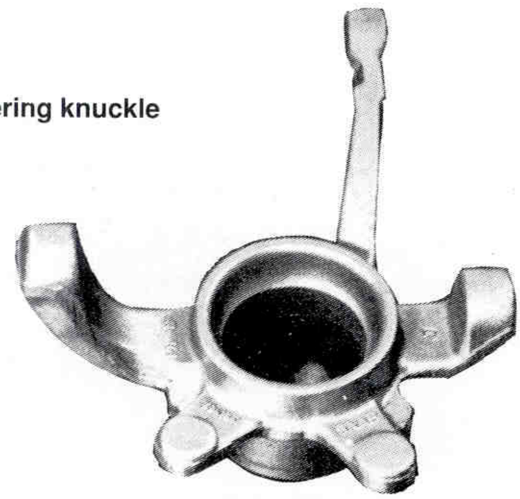
Nitriding is frequently applied to surfaces of components which are subject to severe wear and fatigue conditions because during the nitriding process the forging is heated to a high temperature which results in a smooth surface and good fatigue resistance.

Vanadium "as forged" steels of all carbon levels respond particularly well to this treatment because the vanadium has a high affinity for nitrogen, and this assists the nitriding process.

In order to further assist this process, a small addition of chromium is sometimes made with a corresponding reduction in the manganese content.

Vanadium "as forged" steels, unlike carbon and low alloy heat treated steels, do not need straightening after nitriding treatment. The cost of this operation and the danger of internal stresses which it can produce, are therefore avoided with the vanadium steel.

Steering knuckle



Photograph by courtesy of Volvo AB

Welding of Components

It is sometimes desirable in the manufacture of components of complicated design to weld portions together. This can be effectively carried out with vanadium "as forged" steels using the CO_2 process providing the carbon content is low. Steels with carbon contents in the range 0.30 to 0.35% are adequate.

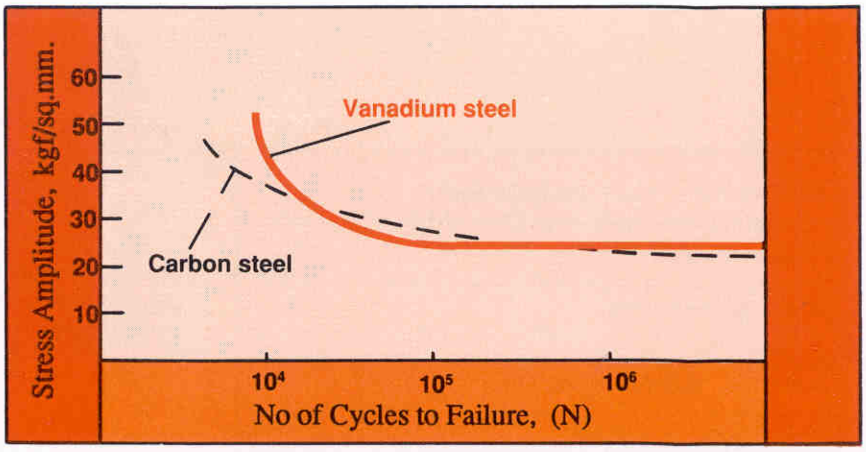
VANADIUM "AS FORGED" STEELS HAVE SUPERIOR FATIGUE RESISTANCE

The improved fatigue properties of both "as forged" vanadium steels, are retained in steels containing additions of sulphur and lead made to improve machinability.

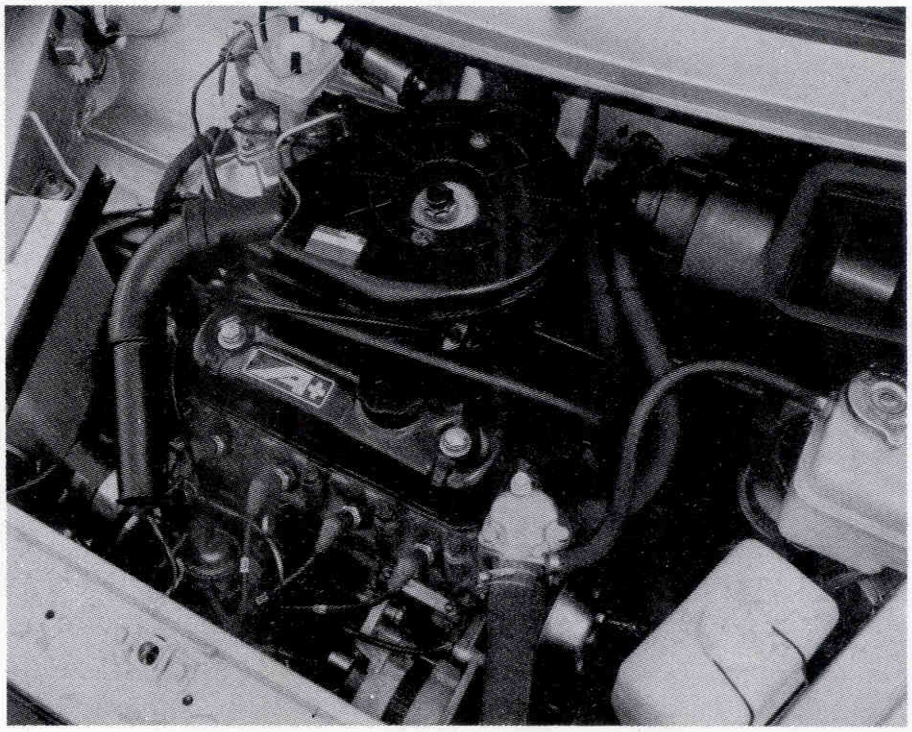
Unlike heat treated carbon and low alloy steels, the fatigue properties of the core of "as forged" vanadium components are not affected by re-heating to temperatures of the order of 400°C. The core properties are also unaffected by nitriding or induction heating processes applied to increase the surface hardness of the forgings.

The fatigue properties of a vanadium "as forged" steels, can in fact be improved by re-heating to the nitriding temperatures and increases of up to 30% in fatigue limit can be achieved as a result of nitriding. The fatigue properties of vanadium "as forged" steels can be further increased by quenching from a higher temperature after the nitriding treatment.

Vanadium "as forged" steels have fatigue resistance at least equal and often superior to the carbon and low alloy heat treated steels of the same tensile strength which they replace.



Fatigue performance of a connecting rod in a pearlite Vanadium "as forged" steel and a heat treated carbon steel



Photograph by courtesy of Austin Rover

Vanadium "as forged" steel crankshaft used in Austin Rover 998 c.c. A-Plus engine

VANADIUM "AS FORGED" STEELS

Replace

Quenched and tempered steels

Across the World

Vanadium "as forged" steels are replacing quenched and tempered steels in Europe, Japan and in North America. In Europe the steels are made to special national standards equivalent to those for quenched and tempered steels of the same strength. In Japan the vanadium as forged steels are supplied to the properies of the equivalent heat treated steels

United Kingdom

BS 970: Part 1 1983 Grade 280M01:
Wrought Steels for Mechanical and Allied Engineering purposes

Chemical Composition

C	Si	Mn	V
0.30/0.55	0.15/0.60	0.60/1.50	0.08/0.20

Mechanical Properties / Equivalent specifications and properties for quenched and tempered steels

Grade	U.T.S. N/mm²	Yield Strength N/mm²	Hardness HB	Impact CVN J	Thickness mm	Grade	Specification
S	925	530	223/277	10	6-19	R	080M40
					13-63	R	150M36
					13-100	S	605M36
					6-63	S	530M40
T	850/1000	560	248/302	8	6-63	T	605M36
					6-29		530M40
U	1075	600	269/331	8	13-63	U	709M40

Germany

Din : Microalloy Forging Steels

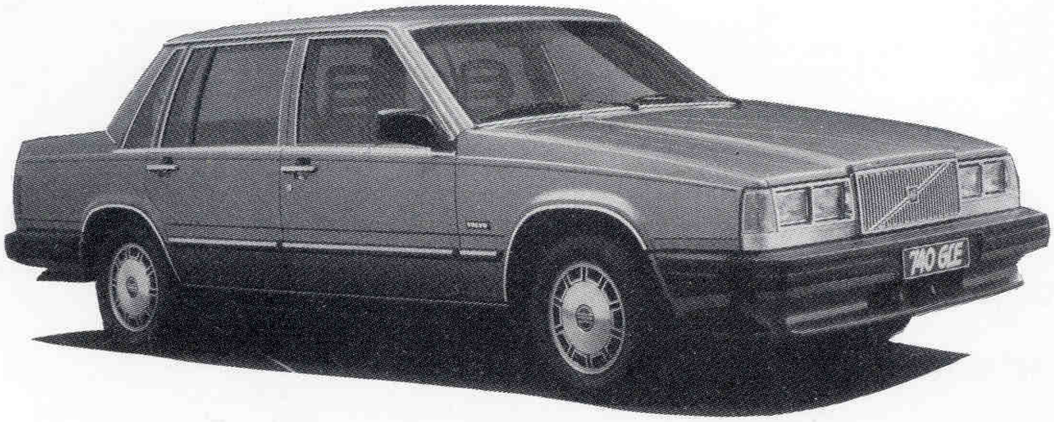
Chemical Composition

Code	C	Si	Mn	P	S	V	Ti
49MnVS3	0.44/0.50	<0.50	0.70/1.00	<0.035	0.04/0.07	0.08/0.13	-
38MnSiVS5	0.35/0.40	0.50/0.80	1.20/1.50	<0.035	0.04/0.07	0.08/0.13	0.02+
27MnSiVS6	0.25/0.30	0.50/0.80	1.30/1.60	<0.035	0.03/0.05	0.08/0.13	0.02+
44MnSiVS6	0.42/0.47	0.50/0.80	1.30/1.60	<0.035	0.02/0.035	0.10/0.15	0.02+

+ optional

Mechanical Properties

Grade	Thickness mm	U.T.S. N/mm²	Yield Strength N/mm²	Elongation %	Hardness Rockwell R_c
49MnVS 3	30-150	750/900	>450	>20	>56
38MnSiVS 5	30-150	820-1000	>550	>25	>52
27MnSiVS 6	30-150	800/950	>500	>30	>48



Photograph by courtesy of Volvo AB.

Some Components Approved for Commercial Production made from Vanadium "As forged" Steels

BMW
Steering arm

K.H.P.
Crankshaft

Mercedes Daimler Benz
Crankshaft (Passenger bus)
Crankshaft (Light trucks)
Con Rods (Passenger cars and trucks)

Mitsubishi
Crankshaft
Con Rods
Front Axle

Opel
Crankshaft

Renault
Crankshaft
Antiroll bar
Tie bar

Rolls Royce
Drive coupling

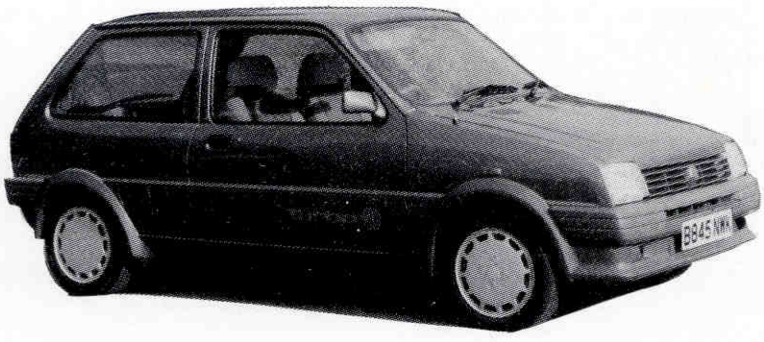
Rover Group
Crankshaft (1.3L Series A)
Steering arm (Metro)

Saab
Crankshaft

Toyota
Crankshaft

Volkswagen
Crankshaft
Con Rods
Steering Knuckle

Volvo
Con Rods
Steering Knuckle
Steering Shaft



Photograph by courtesy of Austin Rover