The Future Competitiveness of Automotive Forgings

Technical Paper Prod/A4

The Future Competitiveness of Automotive Forgings

The Steelmaker's Contribution

By M. Cristinacce, D. J. Milbourn and D. E. James

Over the next decade, the UK automotive supply industry faces great opportunities. This is particularly true of the forging sector, as part of that industry.

Nevertheless, steel forgers must also confront competition from a growing number of alternative material and processes.

For the forgers to exploit the opportunities open to them necessitates not only their vigorous pursuit of process and product development, but also a recognition of the importance of supply chain partnership.

This paper emphasises the equally important role of the steelmaker in that partnership.

This Paper was presented prior to the formation of Corus plc following the merger of British Steel and Koninklijke Hoogovens. Corus Engineering Steels is the new name of British Steel Engineering Steels referred to throughout the text of this paper.

British Steel Engineering Steels supplies 350KTpa of billet and bar to the forging industry. Automotive applications account for around 90% of this volume.

Introduction

The main application of steel forgings in cars is in the power train, suspension and steering system, Figure 1. Typical forged components used in the power train, suspension and steering system of a heavy truck are shown in Figure 2.

Figure 1 Typical forgings in a motor car

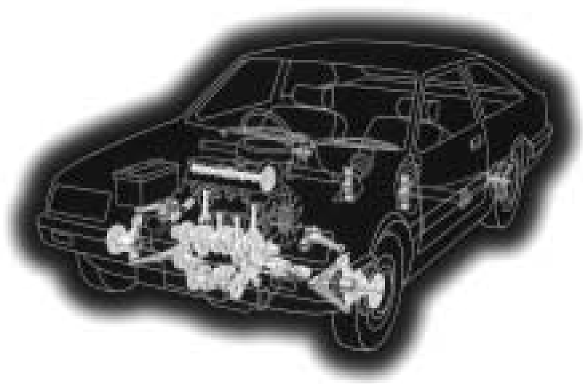
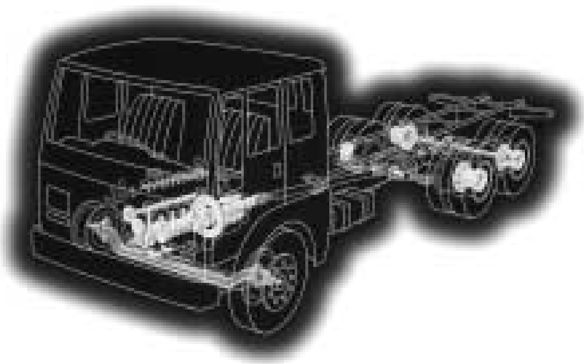


Figure 2 Typical forgings in a commercial vehicle



The Future Competitiveness of Automotive Forgings

Cost has always been important and recent legislation relating to fuel consumption and vehicle emissions has caused weight reduction to gain in importance in the component selection process.

The combined demand for cost and weight reduction in vehicles means that lighter and lower cost materials and processes present an increasingly competitive threat to steel forgings.

As partners in their supply chain, steelmakers and forgers must endeavour to satisfy the automotive manufacturers’ requirements in terms of weight, cost, durability, recyclability and overall performance.

This paper gives some recent examples of where British Steel Engineering Steels has worked closely with forgers and other members of the supply chain, machinists, designers and the vehicle manufacturers themselves, to deliver optimum solutions for the automotive sector.

Traditionally, forgings for engine and suspension components have been produced from heat treated carbon and low alloy steels such as 150M28, 150M36, 708M40 and 605M36, the selection of the steel grade being dependent on the section size of the component and the mechanical properties required. Although heat treated steels are still widely used, air cooled forging steels are increasingly important. Air cooled steels, by eliminating the need for heat treatment, offer significant cost savings through a reduction in energy consumption, fewer process steps and lower inventories. Further cost savings accrue from reduced distortion (and the subsequent need for straightening and stress relieving) and from improved machinability.

Air cooled forging steels

Air cooled forging steels are divided into two basic types, carbon and micro-alloy steels, the latter involving alloying with a small quantity of vanadium. Both form ferrite/pearlite microstructures during controlled air cooling after forging, but the microalloy steels have higher strengths because of the presence of vanadium carbonitride precipitates.

In addition to the cost advantages, the mechanical properties of air cooled forging steels tend to be more consistent than those of heat treated steels, as the forger is able to accurately control forging temperatures and cooling rates.

Working closely with the forging industry and automotive end users, British Steel Engineering Steels has developed a detailed understanding of the effects of composition, forging and cooling conditions upon component properties. [1] [2] [3] Steels are supplied with closely controlled composition to allow consistent properties to be achieved in the finished component.

In the 1980's British Steel developed a range of air cooled microalloy forging steels which it called VANARD [4] - these are widely used, together with other national, international and customers' own specifications.

The Future Competitiveness of Automotive Forgings

Examples of the range of components currently produced from air cooled forging steels are listed in Table 1. Detailed case studies for three specific applications follow.

Table 1 Examples of Air Cooled Forging Steel Applications

Component	Steel Grade	Type
Petrol Engine Crankshaft	Vanard 925	Microalloy
Diesel Engine Crankshaft	38MnSiVS5	Microalloy
Petrol Engine Connecting Rod	080A47/C70S6	Carbon
Diesel Engine Connecting Rod	38MnSiVS5	Microalloy
Diesel Engine Piston Crown	38MnSiVS5	Microalloy
Steering Lever	Vanard 925	Microalloy
Suspension Arm	080A47	Carbon
Hub	S53C	Carbon
Spindle	080A47	Carbon
Swivel Hub	Vanard 925	Microalloy
Drive Flange	38MnSiVS5	Microalloy
Axle Beam	49MnVS3 type	Microalloy

Car Hub and Spindle

An air cooled S53C (SAE 1053 type) has been applied successfully in the production of hubs and spindles for a family sized car. The forgings are produced by John Stokes and Sons Limited of Walsall from steel supplied by British Steel Engineering Steels, and the success of the development has been largely dependent upon close cooperation between the steelmaker, forger and vehicle manufacturer.

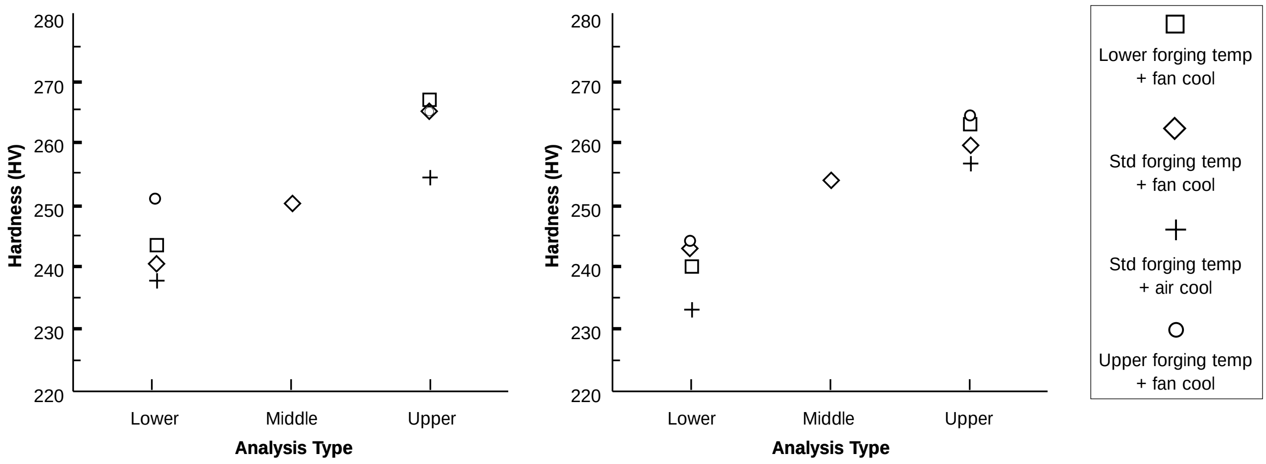
Heat treated forgings are traditionally produced to a hardness range of around 40Hv (50HB). By close control of chemical composition, forging temperature and post forging cooling conditions it is possible to operate to a tighter tolerance when using air cooled steels. In order to demonstrate the maximum potential variation in properties of these components, trials were conducted with steels conforming to the top, middle and bottom of the analysis specification, forged and cooled under a range of different conditions.

The results of this work, which are summarised in Figure 3, show that the hardness specification (230-270Hv) was achieved when using steels with chemical analyses at the upper and lower limits forged using a number of process route variations including high and low forging temperatures and fast and slow cooling. In practice, the chemical composition is controlled to the middle of the range and the forging and cooling conditions are also closely controlled.

John Stokes established a dedicated forging and controlled air cooling line with detailed operating procedures for all critical parameters and consistent hardness values are obtained, well within the specified band. This line is now used for the regular production of these parts which are made at a lower through cost than the previous production method using quenching and tempering.

The Future Competitiveness of Automotive Forgings

Figure 3 The influence of chemical analysis, forging temperature and cooling rate on the hardness of air cooled 0.53% carbon steel hub (top) and shaft (bottom) forgings



Integral Hub

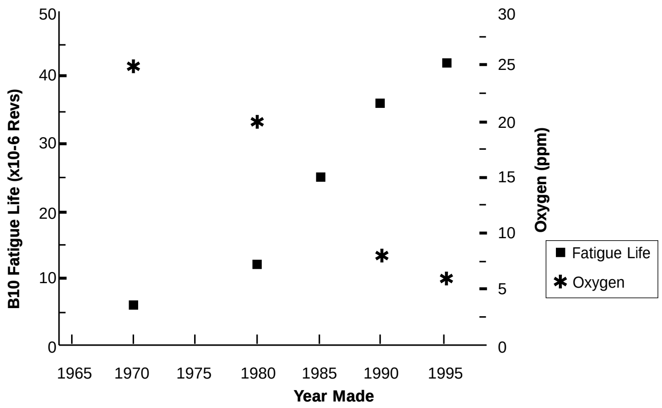
An air cooled SAE 1053 type is also used for the production of integral hub bearings by UEF Garringtons from steel supplied by British Steel Engineering Steels. The forging is shown in Figure 4. In this application the hub forging is machined and induction hardened and acts as the outer bearing race. This design offers lower cost and weight in the finished component compared to conventional hubs which use a separate insert of alloy steel for the bearing outer race. On integral hubs it is necessary for the whole forging to be produced from bearing quality carbon steel, with low oxygen contents and high levels of microcleanness.

Figure 4 Forged integral hub bearing in SAE1053 type

The Future Competitiveness of Automotive Forgings

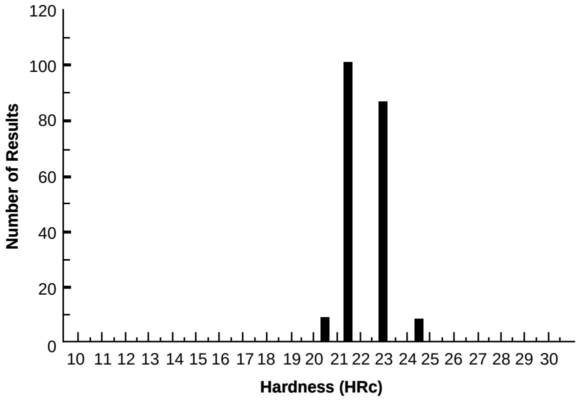
The relationship between microcleanness and fatigue life is well known. [5] Figure 5 shows how year on year improvements in bearing steel cleanness, illustrated by decreasing total product oxygen levels, have been accompanied by steadily rising fatigue lives.

Figure 5 Improvement on oxygen content and rolling contact fatigue life of 1%CCr bearing grade



In addition to meeting the demanding microcleanness requirement, British Steel Engineering Steels is able to supply steel to a narrow analysis range. Using a dedicated press forging line with precision cooling conveyors, Garringtons has developed a stable process route giving consistent and reproducible hardness results. Fine tuning of the analysis has enabled the hardness of the control cooled forgings to be restricted to 20-25HRc (236-262Hv), as shown in Figure 6.

Figure 6 Distribution of hardness results of integral hub bearing forgings



Fracture Split Forged Steel Connecting Rods

A recent development in the manufacture of connecting rods is the use of fracture splitting. This process, whereby the big end cap is removed from the body of the connecting rod by notching, (either mechanically or by laser) and by fracturing, offers major savings in the through-cost of connecting rods. Savings of up to 25% on investment and 35% on processing costs are claimed for connecting rod machining operations. [6]

Table 2 Typical Analysis/Properties of Air Cooled Connecting Rods

	C	Si	Mn	S	V	0.2%PS (N/mm²)	UTS (N/mm²)	El (%)	R/A (%)
080A47mod	.47	.16	.77	.079	-	459	802	16	35
SAE 1045	.45	.21	.74	.032	-	430	781	17	37
VANARD 925	.38	.24	1.25	.070	.094	627	907	22	50
C70S6	.72	.22	.49	.062	.04	530	910	12	20

The Future Competitiveness of Automotive Forgings

Air cooled steels are now well established for use in connecting rods and the use of a 0.70C fully pearlitic steel, C70S6, similar to that originally developed by Ford [7] enables forged steel connecting rods to be fracture split. The compositions and properties achieved in controlled air cooled forged connecting rods are given in Table 2. An example of a fracture split C70S6 connecting rod is shown in Figure 7.

Figure 7 Fracture split connecting rod in C70S6 air cooled grade

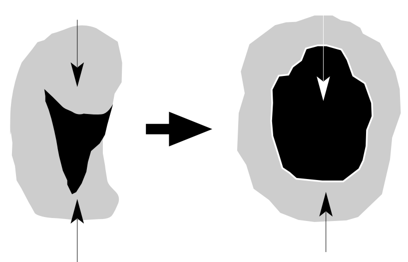
The majority of forging steel for connecting rods supplied by British Steel Engineering Steels is used by UEF Smethwick Drop Forgings and UEF Garringtons. British Steel Engineering Steels has worked closely with UEF on air cooled steels for connecting rods for a number of years and an improved fracture splittable steel grade has recently been jointly developed. The new steel offers improvements in machinability.

The major competition to steel forgings is from sintered powder forgings and the development of a fracture splittable steel has enabled steel forgings to be processed into finished connecting rods at a lower through cost than the powder equivalent.

Improved machinability steels

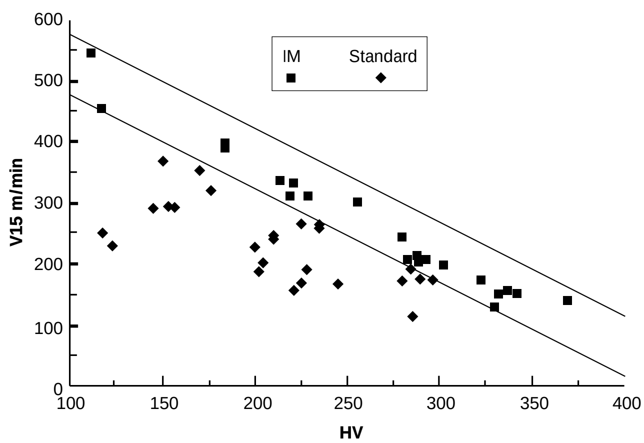
The machinability of a steel component is influenced not only by chemical composition, hardness and microstructure but also by its inclusion species. The IM® steels marketed by British Steel Engineering Steels give improved machinability by calcium treating the liquid steel to modify aluminium inclusions into deformable calcium aluminates. The modified inclusions are often encapsulated by calcium manganese sulphide. Schematic X-ray images of typical inclusions are given in Figure 8. The calcium-modified inclusions have a lubricating effect at the tool tip during machining operations and give significant improvements in tool life or machining speed compared to untreated steels which contain abrasive alumina-type particles. [8]

Figure 8 X-ray images of inclusions in standard and IM low C Mn V steel



The inclusion modification practice, sometimes called "inclusion engineering" is applied to carbon and alloy steels with controlled sulphur levels. The improvements in machinability which can be achieved with IM steels are shown in Figure 9. The speed at which a 15 minute tool life of 15 min (V_{15}) is plotted against hardness, the higher the V_{15} life, the better the machinability. It can be seen that at a given hardness level, IM steels have 20% better machinability than standard steel grades.

Figure 9 Influence of IM treatment and hardness on uncoated carbide tool life of low alloy and direct hardening steels



Cost savings on machinability were achieved on a clutch shaft component by using IM steel The use of IM grade 16MnCr5 in place of standard grade 16MnCr5 gave a 32% increase in average tool life for the broaching operation, ie. 58 components on the IM grade compared to 44 when using the standard grade. This represented a saving of 2.9p per part in tooling and down time on this one machining operation alone.

Hardenability and control of distortion - transmission components

Automotive transmissions which utilise large quantities of steel forgings in the form of gears and shafts are applications where there is little immediate threat from alternative materials, though the demand for lower through costs, lightweighting and the ability to transmit higher loads without any increase in weight is presenting the steelmaker and forger with major challenges.

Most of the components used in these applications are carburised and British Steel Engineering Steels has developed considerable expertise in understanding the relationship between steel composition and hardenability in carburising steels. The hardenability is fundamental in determining the case depth and core properties which are achieved in finished components and most steels for automotive transmissions are made to tightly controlled hardenability limits. This ensures that consistent component properties are obtained from cast to cast. Control of hardenability is also beneficial in the control of an undesirable effect in the heat treatment of carburised components, namely distortion.

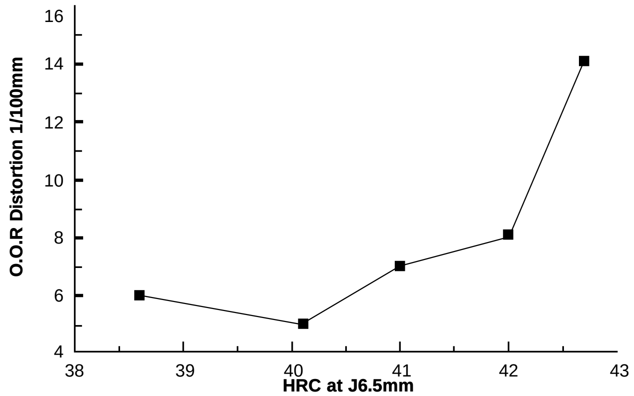
Components which have been heat treated always experience a change in volume and shape as a result of the heating and quenching cycles and from the resulting changes in microstructure. Control of this distortion is critical to the through cost of transmission components. If the distortion is consistent, corrections can be made in the machining processes so that the components distort into "true" on heat treatment. Consistent behaviour from cast to cast and batch to batch is essential. Expensive grinding or "hard machining" processes may be employed to correct for variations in distortion.

The Future Competitiveness of Automotive Forgings

In some cases, correction is not possible, however. A further disadvantage of uncorrected distortion in transmissions is an increase in running noise. This is a major problem for the automotive industry, as “NVH” (noise, vibration and harshness) is being increasingly targeted by legislation.

Whilst most of the control of distortion rests with the machinist and heat treater, two factors are under the control of the steelmaker and the forger: hardenability and macrostructure/grain flow. The effect of hardenability upon heat treatment distortion is well known and was clearly demonstrated some years ago. [9] Recently, British Steel Engineering Steels was asked to produce 20MnCrS5 type carburising steel to a very restricted hardenability range to control distortion in a final drive gear. The gear is made as a ring-shaped forging which is machined and carburised by the vehicle manufacturer. Measurements of “out of roundness” (OOR) or ovality after heat treatment are plotted against the hardness value at the 6.5mm position on a Jominy test curve in Figure 10. It can be seen that as the hardness exceeds a value of 41HRc, there is an increase in the OOR distortion.

Figure 10 Influence of hardenability upon distortion of 20MnCr5 final drive gear



The vehicle manufacturer requires a minimum hardness of 38 HRc at the 6.5mm position in order to meet the design properties of the gear and it is therefore necessary to achieve a hardness range of 38/41 HRc. This is a range of 3 HRc compared to a typical 20MnCrS5 restricted range of 6 HRc at this position and can only be achieved by precise control of composition.

Another factor which can influence distortion in heat treated transmission components is the as-cast shape or macrostructure of the steel. [10] Whilst this factor has been demonstrated to have an effect in a small number of cases, some manufacturers have recognised the effect of macrostructure and the forging process upon distortion of final components. [11] [12] It is reasonable to assume that if variations in the macro structure of the steel feedstock have an influence upon distortion then the flow of material in forging and the subsequent “grain flow” will be of equal importance. The benefits of “monosourcing”, that is a consistent process route for steel and forging manufacture being applied to individual components could have significant benefits in the control of distortion and hence through-costs. This is worthy of further joint study by the steelmaker, forger and vehicle or transmission manufacturer.

The Future Competitiveness of Automotive Forgings

Optimisation of design, processing and material

Collaboration between the designer, forger and steel producer enabled a swivel hub for a multi-purpose vehicle to be redesigned as a forging in place of a steel casting which had been proposed originally.

During the development of this component, Creative Automotive Design of Redditch approached Morgan Platts of Willenhall, West Midlands, who suggested that an air cooled steel forging would offer advantages and British Steel Engineering Steels were invited to contribute on material selection and application.

The steel casting exhibited undesirable characteristics from the outset:

- Unacceptable distortion of the steering arm in heat treatment.
- Surplus material leading to high machining costs.
- Excessive weight, affecting the unsprung mass of the suspension design.

British Steel Engineering Steels recommended the use of VANARD 925, and a redesigned swivel hub was forged and control air-cooled at Morgan Platts. A photograph of the forged swivel hub is shown in Figure 11. The results of mechanical tests on both the forging and the casting are given in Table 3.

It can been seen that forging had superior properties to the heat treated casting.

The swivel hub was designed to meet the following requirements:

a) 3g Pot-hole braking (abuse loading).
b) 3g Full ramp and kerb strike (abuse loading).
c) Kerb jacking (abuse loading).
d) 0.6g Cornering inputs (Fatigue loading).
e) 3g full bump at 0.8g cornering.

Figure 11 Forged swivel hub in VANARD 925 © Creative Automotive Design Ltd.

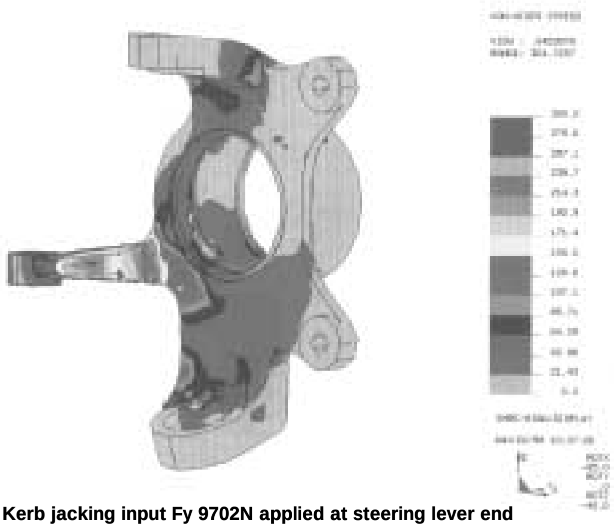
Table 3 Properties of Cast Steel and Forged Steel Swivel Hub

	C	Si	Mn	S	V	0.2%PS Lower YS (N/mm²)	UTS (N/mm²)	El (%)	R/A (%)	3mm U (J)	Hv
Casting (wide arm)	.31	.45	1.34	.014	-	440	655		15-25	63	190-205
Forging (wide arm)	.39	.26	1.28	.075	.099	669	969	17	46.6	9	290-300

The Future Competitiveness of Automotive Forgings

All the above were used as the primary loads in a Finite Element Analysis of the component and a typical mesh diagram is given in Figure 12. Subsequent rig testing of the component included simulated road inputs to determine true fatigue life and a portion of the abuse loading to ascertain the ultimate integrity.

Figure 12 Finite element analysis © Creative Automotive Design Ltd.



Kerb jacking input Fy 9702N applied at steering lever end

The use of a forging gave a number of advantages:

a) Lower weight (a saving of 21% from 4.28 to 3.5Kg).
b) Better dimensional control
c) Less machining.
d) Avoidance of heat treatment costs.

This work showed that by carrying out a simultaneous engineering exercise incorporating the inputs of the designer, forger and steelmaker, steel forgings can achieve optimum solutions in the manufacture of automotive components.

The recent establishment of the British Steel Automotive Engineering Group (AEG) will enable British Steel Engineering Steels to further exploit the combined benefits of material selection, forging and engineering design in future.

Conclusions and future activities

The continued use of steel forgings for automotive applications will depend upon the final cost and weight of the finished components. The examples given in this paper have demonstrated that in considering the whole supply chain, from steelmaker, through forger, machinist to component or vehicle manufacturer it is possible to deliver the lower cost and weight solutions required by the automotive industry.

It will be necessary for this collaboration to be much closer and regular in future if steel forgings are to counter the threats from alternative materials and to meet the increasingly demanding requirements of lower cost and weight.

The following areas of joint activity are expected to be of increasing importance in future:

a) Air cooled steels to be applied to a wider range of components to achieve cost reductions by avoiding heat treatment.

b) Greater application of precision forging to reduce or eliminate subsequent machining operations.

c) More use of improved machining steels, reducing costs on those forgings which require machining.

d) Application of restricted hardenability and monosourcing to carburised transmission components, to reduce the variability in heat treatment distortion.

e) Integration of the component design process to include material selection, forging, machining and heat treatment processes to enable lowest through cost and weight solutions to be achieved.

References

(1) P.E. Reynolds “Alternative Heat Treatment of Metals”, 1990.3, 69-72.

(2) D.J. Milbourn “Air Cooled Steels for Automotive Applications” (Paper presented to British Forging Industry Association Technical Conference, October 1995).

(3) M. Cristinacce, D J Milbourn and P.E. Reynolds “The Current Status of the Development and Use of Air Cooled Steels for the Automotive Industry” Fundamentals and Applications of Microalloying Forging Steels ed. by C.I Van Tyne, G. Krauss, D.K. Matlock, 1996 The Metallurgical Society, Inc. 1996, 29-44.

(4) A. Reeder, C.G. Vasey and D.J. Naylor “Development of Microalloyed Steels for Forging and Bar Applications” Fundamentals of Microalloying Forging Steels ed. by G. Krauss and S.K Banerji, The Metallurgical Society, Inc. 1987, 217-238.

(5) J.M. Hampshire and E. King “Quantitative Inclusion Ratings and Continuous Casting: User Experience and Relationships with Rolling Contact Fatigue Life”
Effect of Steel Manufacturing Processes on the Quality of Bearing Steels, ASTM STP 987 ed. by 3.J.C. Hoo, ASTM, Philadelphia, 1988, 61-80.

(6) “Fracture Splitting of Connecting Rods” Publication by Alfing Kessler Sondermaschinen GmbH.

(7) M.A. Olaniran and C.A. Stickels “Separation of Forged Steel Connecting Rods and Caps by Fracture Splitting” (SAE Technical Paper 930033, 1993).

(8) P.C. Morgan “Free Machining Steels for Consistent Performance” Second International Conference on Industrial Tooling, Southampton Institute, 9/10th September 1997.

(9) W.T. Cook and D.T. Llewellyn “Heat Treatment Distortion in Case Carburising Steels” Metals Technology, May 1979, pp 365/277.

(10) S. Gunnarson “Influence of Continuously Cast Shape upon Distortion of a Case Hardened Steel Crown Wheel” Härt - Tech Mitt. Vol 46 (No.4), p 216-270, 1991 (in German).

(11) J.C. Le Flour “Influence of Flow Lines upon Heat Treatment Distortion” Conference on Heat Treatment Distortion, ATT/AWT, Belfort, France, 24/25th April 1997, pp 119/124.

(12) S. Hock, M. Schulz, D. Wiedmann "Changes in Shape and Dimensions: Some Influencing Parameters and Steps for Predictions" Conference on Heat Treatment Distortion, ATT/AWT, Belfort, France, 24/25th April 1997, pp 125/142.

www.corusgroup.com

Corus Engineering Steels
PO Box 50
Aldwarke Lane
Rotherham
S60 1DW
United Kingdom
T +44 (0) 1709 371234
F +44 (0) 1709 826233
www.corusengineeringsteels.com