Small Scale Manufacture of Replacement Crankshaft

J. A. Nyang'aya[1], G.S. Onyango[2] and A. Oruko[2]

[1]Department of Mechanical Engineering, University of Nairobi, P.O. Box 30197, Nairobi; [2]Central Workshops, Kenya Railways, Box 30530, Nairobi

ABSTRACT

Local production of spares has been recognised to have direct economic advantage for the national economy in which the equipment operates. The crankshaft of a single cylinder diesel engine for which the approximate cost of a replacement is a third of the cost of a new engine was considered a prime product for local development of a production process. A single throw crankshaft of a 6kW diesel engine was designed and casted in spheroidal graphite iron. The casting was subsequently heat treated in two stages for homogenization, and for toughness and strength respectively. The strength properties achieved averaged 750 N/mm^2 with elongation to failure of 2%. A minimum hardness No. of 33 was measured on the Rockwell C. scale. The performance of the crankshaft based on engine bench tests was considered normal.

1.0 INTRODUCTION

It has been recognised that the local production of spares has a direct economic advantage for the national economy in which the equipment operates (Davis 1990) and that provision of local sources of manufacture ensures the availability of spares and maintenance skills (Dunn 1978). The extent of manufacture of spares is however determined by the specific items and the capability of the local industry. To maintain a relevant and competitive role in spite of imports, the industry must continuously improve on the quality of its products and develop new ones.

There exists strong evidence that the mechanization of rural based activities is experiencing accelerated growth. Power plants with typical rating of 7.5kW and in the form of a single cylinder diesel engine, is predominantly sought for use in electrical power generation, water pumping and flour milling. It is on the basis of this need that the liberalization of the national economy, has resulted in massive increase in variety of stationary diesel engines imported into the local market. The currently available number of varieties is considered excessive and has resulted in high maintenance costs, as the after sales services of spares availability and maintenance skills has not matched the influx.

The crankshaft of a single cylinder diesel engine costs approximately a third of the cost of a new engine in the local market. Since such crankshafts could be produced from any of the existing cast iron foundries, it was considered a prime product for which a small scale production process could be designed and developed for local application.

2.0 MATERIAL SPECIFICATION

Crankshafts are made from forgings, or are cast in steel, nodular (spheroidal graphite) iron, malleable or grey iron. With a given design, the strength of the shaft lies approximately in that order. Grey iron is however used only for small low cost engines (Taylor 1985). Generally, cast shafts have the following advantages over steel forgings:-

i) Lower manufacturing costs
ii) Difficult geometries not feasible through forging are achievable.

However, properties comparable with those of steel are only possible if the microstructure is modified, as can be achieved through:-

i) The use of special melting or casting techniques
ii) The addition of alloying elements.
iii) Heat treatment, particularly of white iron (Rollason 1973).

A combination of the above treatment processes is considered adaptable and economical (Rollason 1973). And since nodular iron is very amenable to heat related processing and can be annealed, hardened and tempered, the production process proposed was based on the above heat treatment methods. It has been shown that the structure of grey cast irons is similar to that of ordinary steels but with the addition of graphite flakes which breaks up the continuity of the iron. In a normal grey cast iron the graphite flakes are long and thin, and tend to be pointed at their ends. These long, thin flakes, having negligible tensile strength, act as discontinuities in the structure; whilst the sharp-pointed ends of the graphite flakes introduce points of stress concentration. In spheroidal graphite iron the graphite flakes are replaced by spherical particles of graphite, so that the metallic matrix is much less broken up and the sharp "stress raisers" are eliminated. The formation of this spheroidal graphite is effected by adding small amounts of cerium or magnesium to the molten iron just before casting.

Spheroidal graphite cast irons produced by the magnesium process have tensile strengths of up to 775 N/mm^2 (Higgins 1985).

3.0 DESIGN PARAMETERS

The crankshaft is the most complicated and strained engine part subjected to cyclic loads due to gas pressure, inertia forces and their couples. The effect of these forces and their moments cause considerable stresses of torsion, bending and tension compression in the crankshaft material (Akolchin 1984). The intricate shape of the crankshaft, the variety of forces and moments loading it, the changes which are dependent on the rigidity of the crankshaft and its bearings and some other causes do not allow the crankshaft strength to be computed precisely. In view of this, average proportions empirically derived from practice and experimental stress analysis are used to obtain conventional stresses and safety factors for individual elements of the crankshaft (Taylor 1985, Akolchin 1984, Walshaw 1953, Purday 1948).

The following assumptions are made when designing crankshafts (Akolchin 1984):-

i) A crank is freely supported by supports with the supports and force point located at the centre planes of the crankpins and journals.

ii) The entire span between each support represents an ideally rigid beam.

The following crankshaft design ratios, based on application of test results and empirically derived relationships, were used for the present design:-

i) The crankpin diameter should be at least 0.6 times the bore. Crankpin length should be enough to accommodate connecting-rod bearings of not less than 0.30 times the crankpin diameter (Akolchin 1984).

ii) The main journal diameter should be 0.67 times the bore (Purday 1948) while the main journal length can be as short as 0.3 times the journal diameter when centrifugal crank loads are counterbalanced.

4.0 CASTING PROCESS DESIGN

Several considerations were necessary to determine the suitable casting orientation, these included solidification pattern, gating and feeding.

4.1 Solidification Pattern

A vertical orientation of the pattern with the smaller section of the casting being at the bottom was preferred. This position promoted solidification from the bottom and facilitated the preferred orientation of the crystals. A schematic layout of the assembled mould is shown in Fig. 1.

4.2 Gating

A down sprue with a bottom gating passing via a well, was chosen. This ensured quiescent entry of metal into the mould, thus minimizing turbulence, mould erosion and gas defects.

4.3 Feeding

Atmospheric feeder head was placed at the top of the casting, to counter any shrinkage introduced by the solidifying of metal from the bottom of the mould.

4.4 Moulding

The vertical orientation of casting required that chemically bonded, cold setting sand be used. The mould was coated with silicon based refractory wash in order to improve the surface finish.

4.5 Casting

The desired grade was of normalised pearlitic spheroidal graphite iron, with strength properties of between 700-800 N/mm^2 and a minimum elongation to failure of 2%. Copper was used as a pearlite former and inoculation using foseco inoculant done in the ladle. The purpose of inoculation was to refine the structure during cooling so that a tougher structure could be obtained. The metal was introduced into the mould after treatment with ferro silicon magnesium at between 1420 and 1450°C.

5.0 POST CASTING HEAT TREATMENT

Heat treatment was done in two stages. The first stage was to anneal as well as homogenise the structure. The second stage heat treatment was to enhance the strength and toughness properties of the casting. Machining was carried out between the two stages. Photographs labelled Fig. 2 and 3 shows a crankshaft as it appears during these stages.

5.1 Homogenization Heat Treatment

The casting was heated slowly to austentisation temperature of 850°C and then held at that temperature for 3 hours (Rollason 1973). The furnace was then switched off and the casting allowed to cool with the furnace. A similar cast material from the same melt was put alongside the casting for testing purposes. The casting structure was examined under a metallurgical microscope after annealing and compared with the as cast structure.

The microstructure of the as cast structure examined away from the skin revealed directional dendritic structure and fairly coarse grains revealed under magnification of x 400. The skin structure had a high level of cementite encouraged by the high rate of cooling. The annealed structure was equally coarse but the structure was equiaxed. Both structures were pearlitic.

5.2 Heat Treatment for Strength and Toughness

The crankshaft was given an initial heat treatment to facilitate machining. Subsequently, and during machining the journals were sized approximately 2 mm larger than the final sizes, before performing the second stage heat treatment. The oversize was required to take care of the decarburized and scaled surface, obtained during the second stage heat treatment within a non-inert atmosphere in an electric resistance furnace.

The crankshaft was heated slowly to 900°C and held at the temperature for 1.5 h to allow austenitisation. The austenitised crankshaft was removed and immediately quenched in oil while vigorously agitating the quenching media. After cooling, the crankshaft was returned to the furnace and maintained at 400°C for tempering for 2 h.

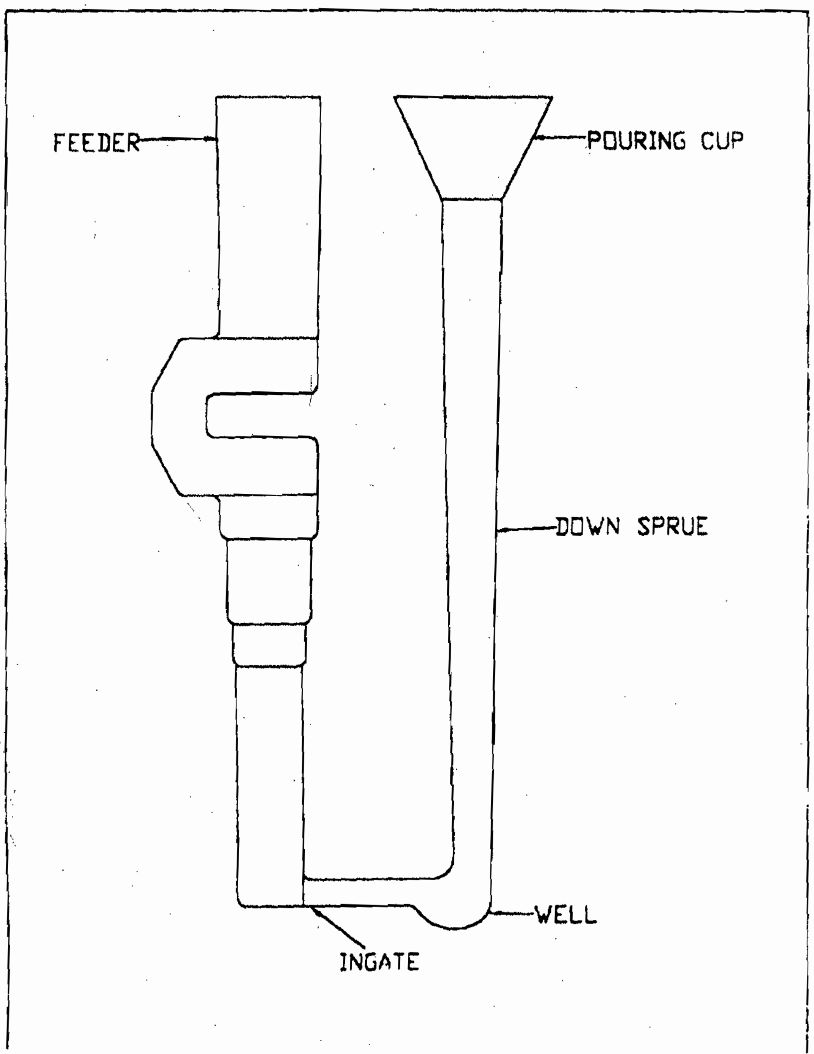

Figure 1. Schematic diagram of the orientation of pattern

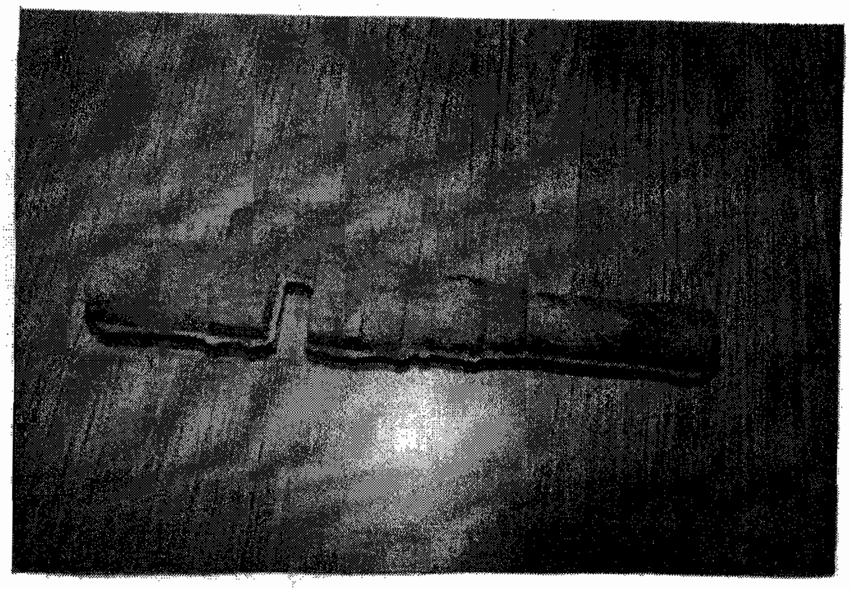

Figure 2. Crankshaft as appears after casting, fettling and initial heat treatment

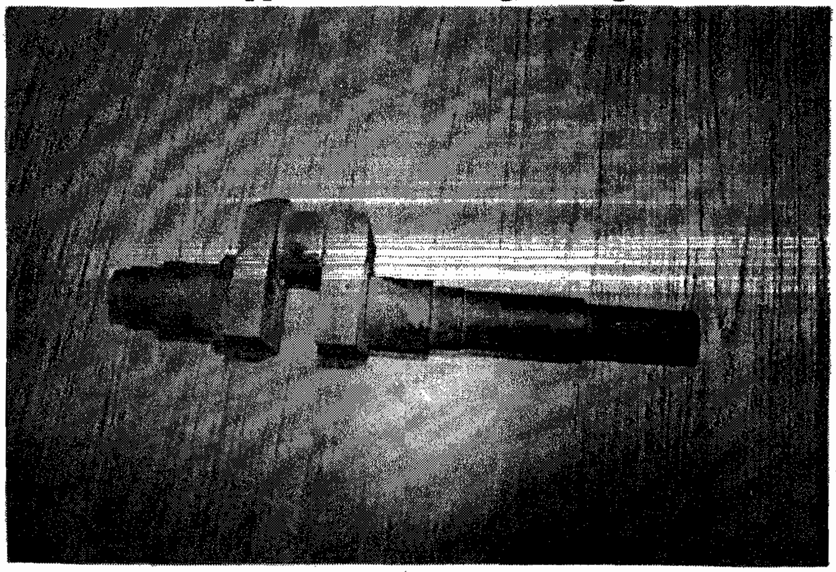

Figure 3. Crankshaft as appears after machining and second heat treatment

6.0 DISCUSSION AND CONCLUSION

The as cast structure of the crankshaft prepared for the microscopic examination and etched in 5% Nital revealed graphite spheroids in a matrix of pearlite. The vertical orientation of the crankshaft during casting produced the crystal structures of varying sizes and graphite concentrations. The crankshafts were therefore given the homogenization and grain refinement heat treatment before undergoing the hardening and tempering processes for strength and toughness.

The prepared microstructure for the examination under the metallurgical microscope revealed graphite nodules in a matrix of tempered martensite.

The hardness number recorded after post casting heat treatment ranged between 31 and 33 on the Rockwell C. scale with the corresponding tensile strength of 700 to

800 MPa. The average elongation recorded was 2% on the prepared test bars. The relatively lower strength was aimed so as to gain additional toughness in the crankshaft. The application area of the crankshaft of single cylinder engines without the advantage of uniform loading such as in multi-cylinder engines requires toughness to absorb the shock loads.

The crankshaft was subsequently installed in a test engine for bench trials. At the rated speed of the engine of 1800 revolutions per minute, the engine was ran for an approximate duration of 100 h. During the period, the crankshaft was removed four times for inspections and no untoward scratches, wear or cracks were observed on all bearing surfaces.

Notwithstanding, the need to conduct more arduous field tests, it was concluded that the manufacturing process used has potential for low volume production of quality crankshafts.

ACKNOWLEDGEMENTS

We are indebted to the University of Nairobi and Kenya Railways for providing the facilities to carry out the work.

REFERENCES

Akolchin V. Demidov (1984) Design of Automotive Engines MIR Publishers, Moscow.

Davis R.J. (1990) Design Specification for Small Diesel Engines Operating in a Rural Environment 3rd International Conference on Small Engines and their Fuels for use in Rural Areas, University of Reading ,UK ,17-19.

Dunn P.D. (1978) Appropriate Technology - Technology with a Human Face. The Macmillan Press Ltd. 1978.

Higgins R.A. (1985) Engineering Metallurgy Part 1,Applied Physical Metallurgy, Hodder and Stoughton, London, 1985 .

Purday H.F.P. (1948) Diesel Engine Design, Constable and Co. Ltd.

Rollason E.C. (1973) Metallurgy for Engineers, English Language Book Society.

Taylor C. F. (1985) *The Internal Combustion Engine in Theory and Practice -* **2**, The M.I.T. Press.

Walshaw T.D. (1953) *Diesel Engine Design*, George Newness Limited, London.