The application of high-strength cast irons (ADI - austempered ductile iron) in high-performance diesel engines – part 2

Designing engine cradles for a high-performance ship diesel engine with high strength ADI (austempered ductile iron) cast iron material, results in a weight advantage of 30% compared with previous series solution results. Additionally, the manufacturing costs are clearly reduced.

Part 1 of this article appeared in the October issue of Foundry Trade Journal.

In part 1 of the article, the authors provided details of the engine-cradles (model MTU Friedrichshafen Ltd, series BR 8000), materials selection, manufacturing and features of ADI and an ADI-suitable component dimensioning.

Simulation tools

FEM was used to calculate the possible static and dynamic loading and the component was redesigned with regard to the chosen casting method. Adjacent components like the elastic engine bearing and the crankcase, as well as the resulting pre-stress force of the screwed joint, were included in the FEM calculation.

Fig. 5 shows the result of a loading case calculation (screwed joints are blanked here). The motor cradle bearing connection is subjected to a vertical force emanating from the motor bearing. In spite of this stress the highest tensions are produced during assembly pre-stressing. These are located at the side sections screw bearing surfaces in the form of compression stresses. Further highly stressed areas are situated at the interface of the ribs to the base plate and at the bearing connection. The height and distribution of the tension remain at a non-critical level for ADI-800, however, because of the design.

The component development has been supported by the use of casting and solidification simulation. For optimal quality of the component, a constant die filling (position and geometry of feeder, etc) as well as an adjusted solidification in section and feeder have to be achieved in particular. The simulation can reveal potential problem areas like an isolated centre of heat, on which the formation of cavities and porosity can occur.

For optimal quality of the component, feeder and heat sinks are established whose size and position are determined with the aid of the simulation. A snapshot of the solidification simulation is shown in fig. 6. Three feeders are used in total, of which one is located on each of the side sections and another on the bearing connection. Furthermore heats sink are placed on the base plate and the bearing surface as well as the engine mounting. The temperature gradient from the cooling elements facilitates solidification to the feeders. Possible micro-porosities are displaced to uncritical areas such as in the interior of the side parts. According to the FEM simulation, these areas experience a lower load, so that potential porosities are not critical to the performance of the component.

Production of prototypes

The prototypes were cast at Eisengießerei Hulvershorn GmbH & Co KG in Bocholt, Germany, which specialises

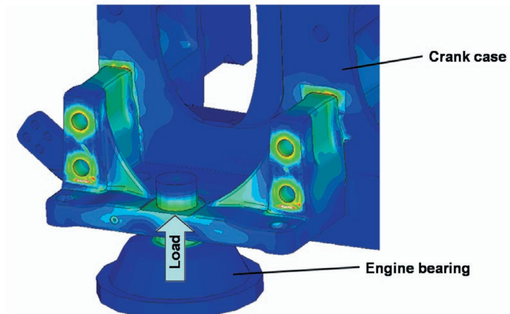

Fig. 5. Stress distribution (cross section) resulting from vertically applied load at the bearing connection and pre-stresses. The highest stress (compressive) occurs on the screw surfaces on the side sections as well as in the bearing connections and the webs. The strain level is not critical to the design condition

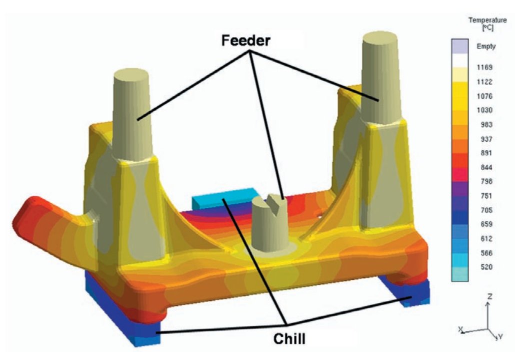

Fig. 6. Solidification simulation indicating temperature profile after 18 minutes. By appropriately positioning the feeders, and the use of chills, the desired solidification pattern is achieved

Fig. 7. Moulding plates for the broad engine cradle made from ADI with interchangeable shackle (right or left)

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Fig. 8. Cast engine cradle made from ADI-800 (machined) with left shackle (cast at Eisengießerei Hulvershorn, Bocholt, Germany; heat treated at ADI Treatments Ltd in England)

in large and sophisticated ADI-components. The heat treatment was carried out at ADI Treatments Ltd in Birmingham, England; the company is a subsidiary of the Bocholt foundry, ensuring co-ordination from the outset between founder and heat-treater. This is essential for successful production of ADI.

Fig. 7 shows the adjustable moulding plates with adjustable component for the broad variant of the engine cradle with a shackle. The tool for the shackle can be attached on the left or the right side on the mould according to requirements. The casting dies, in furan resin bound quartz sand, are produced on a mechanised moulding facility. Machining is performed on a five-axis CNC machining centre in two clampings. The completely machined ADI cast engine cradle with left shackle is shown in fig. 8.

Through the systematic application of CAX-tools and the utilisation of the material potential of ADI, a weight reduction to 85kg (30%) is achieved, compared with the conventional construction of some 126kg. The integrative cast construction with the ADI material also gives cost savings in the manufacturing of the component. This is achieved through a reduction of the amount of single components and therefore the reduced joining and treatment operations.

Component characterisation

The comparison of material variables, which were found by destructive material testing with the given standard value of DIN EN 1564, more than confirms the achieved quality of the material. Tensile tests according to DIN EN 10 002, which were extracted from several component areas (amongst others bearing connection, web structure etc) show an average value of 645N/mm² yield stress for 0.2 % elongation (standard specification EN-GJS-800-8: 500N/mm², see table 1) and for the tensile strength an average of 900N/mm² (standard specification EN-GJS-800-8: 800 N/mm²).

The standard specifications are exceeded on different parts of the component. The fracture point is also above the standard specifications of 8% elongation in all regions. The appropriate microstructure examinations confirm the results of the tensile tests, because all tested ranges, even the range of maximum wall thickness of approximately 80mm, show a well formed and persistent ausferrite structure.

Fig. 9 shows the ADI structure, consisting of ferrite needles in an austenite matrix as well as nodular graphite. The structure test was performed in the region close to

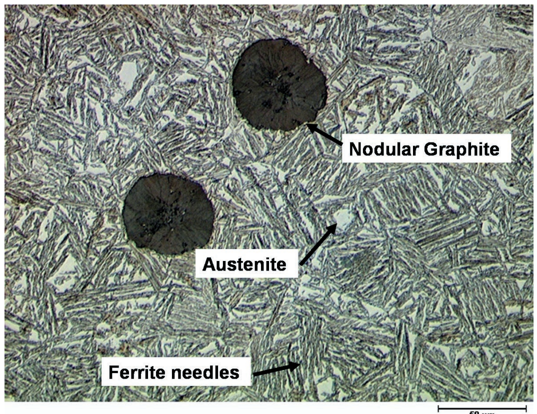

Fig. 9. ADI structure in the region of the middle bearing connection beside the drilled hole

the surface of the middle bearing connection, adjacent to the drilled hole.

Endurance test on the component

The endurance tests were conducted on a dynamic endurance test bench, on which two engine cradles were tested in parallel in double load. Fig. 10 shows the test bench with the clamped engine cradles (the engine cradle in the back is rotated 180°C relative to that at the front, so that it is almost obscured in this figure). The vertical cyclic load per engine cradle was 1.7 times the required specific load and was endured by the engine cradles without damage.

The subsequent crack test in lime water revealed no evidence of cracking. The ultimate number of load cycles,

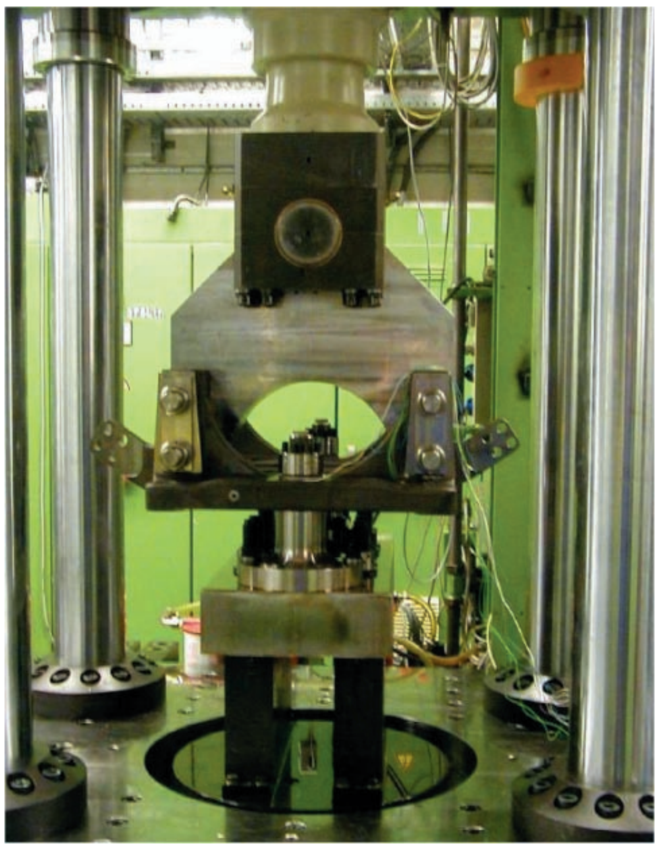

Fig. 10. Test bed for fatigue test at MTU Friedrichshafen Ltd with two clamped engine cradles (the second engine cradle is largely obscured). The parallel mounting allows the concurrent testing of both engine cradles within excess of 1.7 times the power in the vertical direction

(10 million cycles), was achieved free of cracks. Therefore the endurance of the ADI engine cradle was proven.

For the final engine tests at MTU in Friedrichshafen, an engine at the engine test bench was loaded with a complete set of ADI engine cradles. Special acceleration sensors were used for a variety of structure borne ultrasonic measurements on the engine cradles among others. In spite of significant weight reduction, the natural frequency and noise amplitude emissions are comparable with the steel engine cradles and are consequently in the acceptable range.

Based on the component and bench tests, the ADI engine cradles for commercial applications in shipping (ferries, yachts etc) were released at MTU. In addition to considerable cost reduction, the total engine weight was reduced by approximately 300kg.

Summary

Operating stresses were simulated through detailed FEM calculations of the critical loading scenarios and the geometry was optimised accordingly. In addition to the calculation of loading scenarios, the casting, feeding and cooling processes, which are necessary for good component and material quality, were designed with the help of casting and solidification simulation. As such, the ADI engine cradle contains all functions of the welded and screwed steel alternative.

Destructive testing confirmed the component and material quality of the engine cradle of EN-GJS-800-8 according to DIN EN 1564. The required endurance limit of the ADI engine cradles was demonstrated by subsequent vibration fatigue tests. On an engine loaded with ADI engine cradles, structure borne ultrasonic measurements yielded frequencies and emissions in acceptable ranges and so enabled the ADI engine cradle to be approved for series manufacture.

ADI is a cast iron material that offers a high potential for cost and weight reduction in many applications compared to the conventional use of steel and aluminium. In addition to the substitution of existing components, the application spectrum of ADI is set to expand for current and future developments for high performance diesel engines at MTU as a highly cost effective material alternative.

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