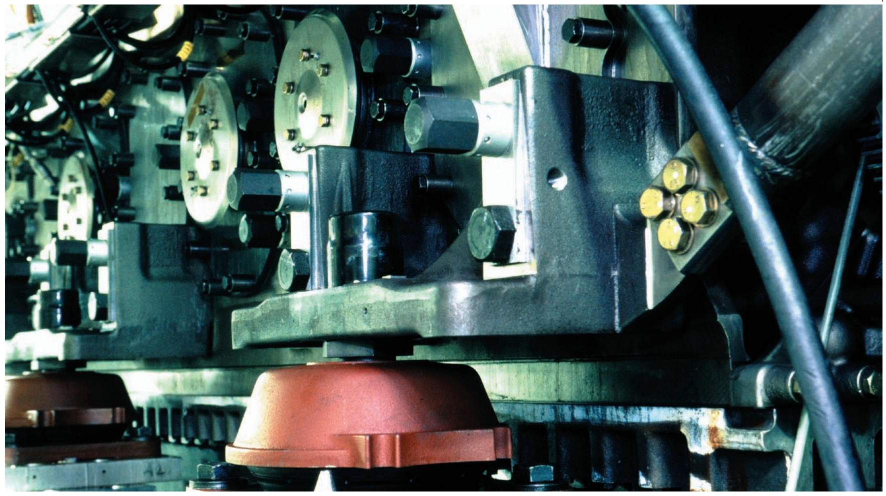
The application of high-strength cast irons (ADI - austempered ductile iron) in high-performance diesel engines – part 1

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. This case study illustrates the added value of the austempering process when carried out as a post casting heat treatment.

Part 2 of the article will appear in the November issue of Foundry Trade Journal.



Engine cradle for the high performance Diesel motor made from ADI *(model MTU Friedrichshafen Ltd, series BR 8000)*

In the year 2000, MTU Friedrichshafen Ltd introduced the model range 8000 (fig. 1). This is a high-performance diesel engine in a 20-cylinder-V-construction based on the common-rail technology with a power rating up to 9000 kw. Its primary application is fast, commercial ships and is also used in marine navigation and yachts.

In commercial applications, the engine is connected by a total of eight engine cradles (four on each side) to the body of the ship. This arrangement transmits the reaction forces and momentum to the ship's foundation.

The engine cradle steel construction, steel basis S355J2G3 according to DIN EN 10025, comprises several single components which are welded or screwed together (fig. 2). The base plate is welded with two side-sections with two through-holes in each section. These are used to screw the engine cradle to the crankcase. A connecting link welded to both side sections and the base plate serves as reinforcement.

The base plate has several holes, of which the one in the centre is intended for connection to the engine suspension. Two of the eight engine cradles always possess a shackle, which is screwed on the right or left side. The momentum generated by the rotating exhaust turbocharger, at the engine clutch side, is braced by the shackle.

The remaining six engine cradles are identical in construction, except for a shorter width. The steel-engine cradles with shackle consist of six single components (four without shackle). In addition to the actual joining process, preparation and subsequent mechanical post-processing of the weld seams is required. Due to the high manufacturing costs and the variety of parts for a steel cradle, an alternative design in the form of an integrative cast component was conceived.

As component design change would lead to significant costs for the small and medium number of pieces, the new design needed to provide not only equivalent component-performance, but also considerable cost and weight advantages.

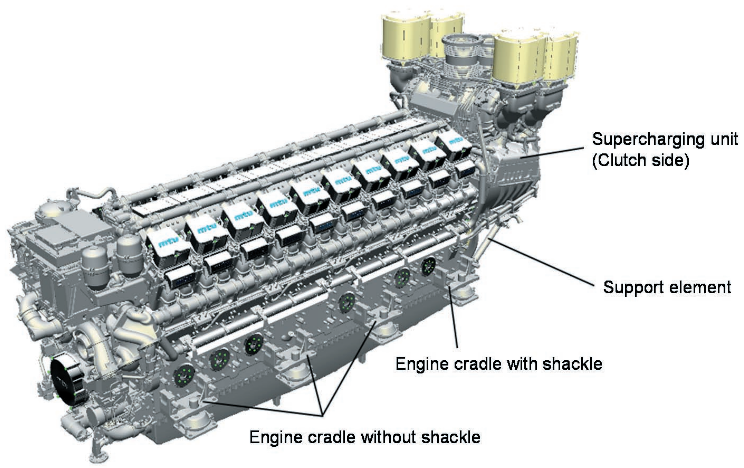


Fig. 1. High performance diesel engine (Model MTU 20V 8000) with four engine cradles each side. One engine cradle is shown with mounting supports for the overlaying transmission turbocharger and inter-cooler bracing

Material selection

In order to reduce the number of single components in the steel engine cradle and with it the associated pre-processing, joining and post-processing operations, the engine cradle should be produced as an integrative cast component in the future. The shackle can then be cast as required on the right or left side of the engine cradle by using an interchangeable component at the set-up stage. Because of the required high strength and obvious weight reduction, the innovative cast-iron material ADI-800 (austempered ductile iron, EN-GJS-800-8 according to EN 1564) was chosen.

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ADI is a heat-treated cast iron with nodular graphite. In comparison with pearlitic cast iron with nodular graphite and is characterised by significantly higher static and dynamic strength and a higher ductility at the same time. This is proven to be essential, particularly for the required zero damage rate. Therefore the material ADI-800 is preferred for this application and also with regard to lightweight-aspects.

Furthermore, this material offers better characteristics concerning noise- and vibration-damping than steel. This is an advantageous characteristic, particularly for components in the engine suspension region. In spite of the material heat treatment for lightweight variants, the manufacturing costs of ADI cast parts can compete with conventional materials. Compared with steel and aluminium, ADI has a lower price per kilogramme (based on the attainable yield point of the material).

Manufacturing and features of ADI

Pearlitic cast iron with nodular graphite forms the basis for the production of ADI materials. It may be necessary to use a small amount of nickel and/or molybdenum alloying elements (depending on the maximum wall-thickness of the component) during the heat-treatment process.

The central component of the manufacturing of ADI is a three-stage heat-treatment (fig. 3). Firstly the component is heated to the austenite region at 900°C and held there for at least two hours, in order to enrich the initially low-carbon austenite with carbon. Afterwards it is transferred immediately to a salt bath with an exact temperature between 240 and 390°C and held isothermally for at least 1.5 hours. During this period, ferrite needles separate from the austenite until equilibrium is reached.

The resulting composite structure is referred to as ausferrite. Depending on the selected temperature of the salt bath, the required mechanical features of the material ADI can be achieved. The result of using higher temperatures in the intermediate stages (salt bath with approx. 360 to 380°C) is the desired ADI-800 with high ductility (table 1). Using several salt-bath-temperatures, ADI-grades can be divided into five (ASTM A 897M-90) or four (DIN EN 1564) categories.

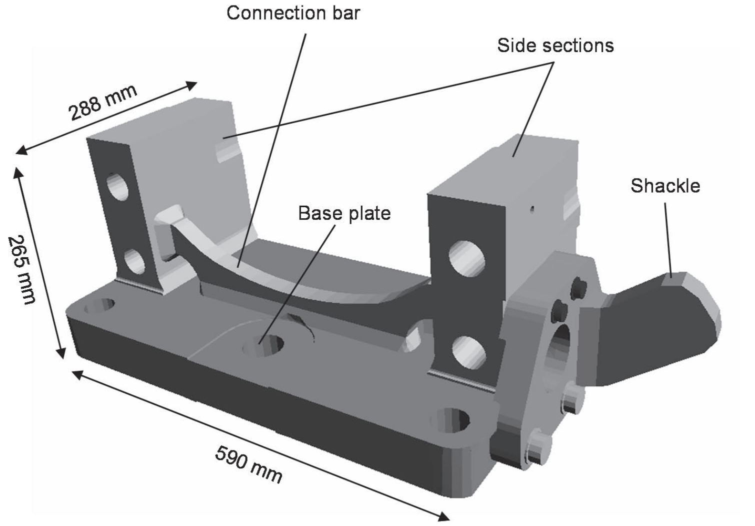

Fig. 2. Engine cradle (machined) with base plate, side sections left/right, each with two through-holes as well as welded brace and right shackle which is screwed on

ASTM A 897M-90	DIN EN 1564	Tensile strength R_m [N/mm²]	Young's modulus $R_{p0,2}$ [N/mm²]	Elongation A_5 [%]	Hardness[1] Brinell HB	Charpy Impact[2] A [J]
	GJS-800-8	800	500	8	260 - 320	-
Grade 1		850	550	10	269 - 321	100
	GJS-1000-5	1000	700	5	300 - 360	-
Grade 2		1050	700	7	302 - 363	80
	GJS-1200-2	1200	850	2	340 - 440	-
Grade 3		1200	850	4	341 - 444	60
	GJS-1400-1	1400	1100	1	380 - 480	-
Grade 4		1400	1100	1	388 - 477	35
Grade 5		1600	1300	-	444 - 555	-

1) Reference values
2) un-notched charpy- samples at room temperature

At present uniform standards in preparation (ISO/WD 17804) with the following 5 grades:
Grade 800-10; 900-8; 1050-6; 1200-3; 1400-1

Table 1. ADI Standards

At present, the ISO/WD 17804 is aiming to achieve simplification of the standard. The most important factor for the factory production of ADI is the exact balance between the component related, chemical alloy-composition and the parameters of the heat-treatment. The quenching speed has to be so high that no pearlite is formed. For thick-walled components in particular, this is provided by an accurately controlled addition of alloying elements like copper and a small amount of nickel and molybdenum. This causes pearlite not to form even at lower cooling rates, so that the continuous heat-treatment can be ensured for thick-walled components.

The exact stop-periods and temperatures are dependent on the component geometry and the selected alloy composition. A continuous communication between founder and heat treater is crucial for process safety. Appropriate fully-automatic and computer-controlled heat-treatment facilities are also required for the setting of the desired ADI-structure. These can be operated with precision and give reproducible results for the austemper-heat-treatment process.

ADI-suitable component dimensioning

In order to keep the manufacturing costs low, a hollow construction is chosen. Fig. 4 shows the cast-geometry of the broad engine cradle with a shackle on the left side. In this broader variant, the shackle is cast with an interchangeable component

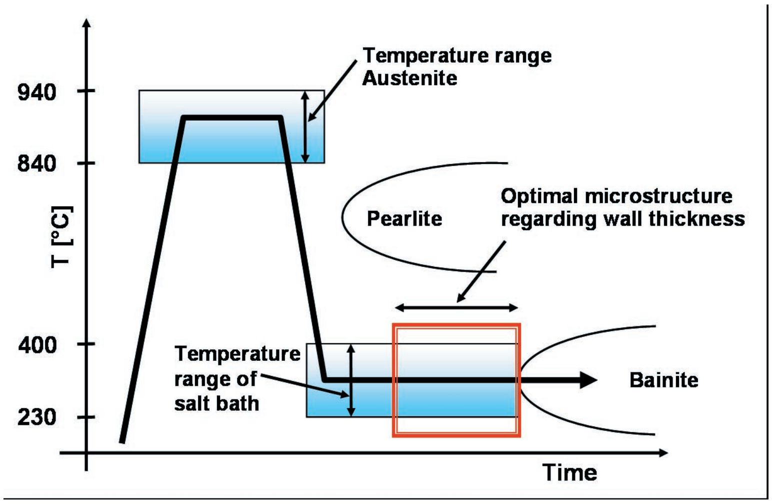

Fig. 3. Schematic of the temperature gradient of the isothermal interstitial transformation

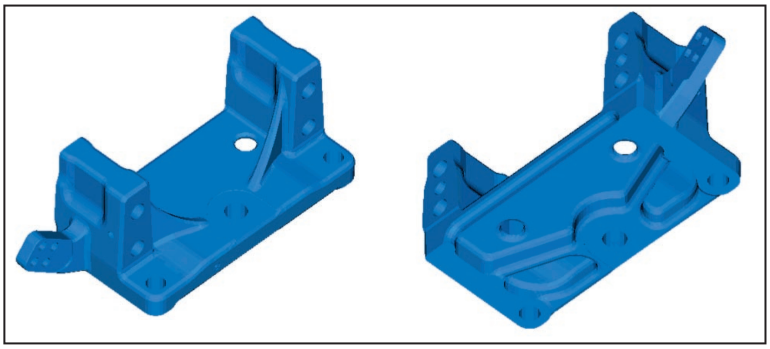

Fig. 4. Single component motor cradle cast using ADI with left founded shackle; (left) view from above with webs between the side sections and the bearing connection. The side sections have pockets on both sides; (right) view from below with wall thickness reduced base plate and ridge structure for rigidity

to the mould either on the right or the left side of the side section. The two interior openings of the base plate are predefined by the casting pattern.

Because of the forces acting between crankcase and bearing, webs in the direction of the bearing connection are located between the side sections and the central bearing connection. A definite weight reduction on the base plate could be achieved by a reduction of the wall-thickness. In order to simultaneously guarantee the conservation of rigidity, the lower side was provided with a rib structure. Pockets were inserted on both sides of the side-sections to provide further weight reduction and production optimisation.

Additionally, the pockets improve the solidification procedure and offer a better heat dissipation during the heat treatment because of the reduced wall-thickness.

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In part 2 of the article, the authors provide details of the simulation of the casting, ADI properties and endurance testing.