

MANUFACTURING

Sigma GTDi Engine Block

P101973

Ford Motor Company

Abstract

In this report research was carried out into the high pressure die casting process that Nemak carry out to supply Ford Motor Company with the Sigma GTDi engine. Details on the specification's Ford require from Nemak. A quality issue of material shrinkage is detailed, and the relative process followed.

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Introduction

In this report the manufacturing process of the Ford Sigma 1.6 & 1.5 Ecoboost engine block will be discussed and justified. Relevant information in regard to materials, quality issues, specifications and volume will be given.

Product

The Ford Sigma engine has been around since the early 90's and is still used today. The 1.6 & 1.5 litre GTDi are the two main derivatives which are still be produced in high volumes over the globe. Due to the good performance figures, high fuel economy and low emissions the Sigma engine is very popular throughout the ford range.

Due to the volume of Sigma engine the process of manufacturing must be one which allows for consistent high levels of accuracy and capable to cope with high volumes. Bridgend Engine Plant (BEP) produce 511,000 (Campbell, 2017) Sigma engines a year. The derivative split is decided on a monthly basis. Ford outsource the casting process to NemaK who are one of the world's biggest automotive component manufactures. They supply Ford with not only the Sigma engine but almost all their engines, this is mostly due to ford being a stake holder (NemaK, 2018). NemaK also supply other manufactures such as GM, Fiat-Chrysler, VW Group, Hyundai-Kai, BMW, Renault-Nissan and Daimler-Benz. As seen NemaK produce components for all the automotive giants and are industry leaders in the innovation in casting Aluminium.

Required Specifications

Here are the details of the required specification that Ford set to Nemak. The specification data comes from the block data sheet.

General Casting Tolerances

CASTING-TOLERANCE														
RANGE OF NOMINAL DIMENSION	TO 18	OVER 18 TO 30	OVER 30 TO 50	OVER 50 TO 80	OVER 80 TO 120	OVER 120 TO 180	OVER 180 TO 250	OVER 250 TO 315	OVER 315 TO 400	OVER 400 TO 500	OVER 500 TO 630	OVER 630 TO 800	OVER 800 TO 1000	OVER 1000 TO 1250
DEPENDENT TO MOULD PARTING LINE	±0.25	±0.35	±0.4	±0.45	±0.55	±0.65	±0.75	±0.8	±0.85	±0.95	±1.1	±1.2	±1.4	±1.6
NON-DEPENDENT TO MOULD	±0.55	±0.65	±0.7	±0.75	±0.85	±0.95	±1.0	±1.1	±1.1	±1.2	±1.4	±1.5	±1.7	±1.9

THE TOLERANCE OF CAST BORES AND BOSSES DIMENSIONED IN RELATION TO DATUM $\boxed{K}$ $\boxed{L}$ $\boxed{N}$
REFER TO CASTING DATUMS $\boxed{X}$ $\boxed{Y}$ $\boxed{Z}$  STOCK INDICATION

GENERAL ROUGH PART TOLERANCES $\begin{matrix} +1 \\ -0.3 \end{matrix}$ IF NOT OTHERWISE SPECIFIED

(Ford Motor Company, 2009)

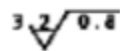
Wall thickness ± 0.5 mm

Crankcase wall thickness ± 0.5 mm

Draft angle 2° Max

Contour angle $\pm 1^\circ$

Surface finish:



(Ford, 2018)

Diameter, depth, shape and position of pre-cast core-pins for thread moles, including tolerances, are left to supplier's discretion. But must be measured prior to shipping.

Material Specification

The material must be WSS-N2A165-A Aluminium with the following chemical composite added:

- Si 8.0.. 9.5%
- Fe 0.6.. 1.0% Max
- Cu 2.75.. 4.0%
- Mg 0.15.. 0.35%
- Mn 0.2.. 0.4%
- Ni Max.. 0.3%
- Zn Max.. 1.15%
- Sn Max.. 0.2%
- Ti Max.. 0.2%
- Cr Max.. 0.05%

Tensile Strength a minimum of 200 MPa

0.2% Proof stress, minimum of 150 MPa

Elongation minimum 0.7%

Hardness of 80-120 HBS

Blocks are air cooled.

Subsequent ageing process at 220°C for 2.5 hours.

(Ford Motor Company, 2009)

Visual Specification

Ejector pin marks are not permissible in datum and clamping areas.

Ejector pin marks may be under flush or protrude within general casting tolerance.

All cast identifications to be 1.6 min raised characters.

To achieve the required specification, Nemaq high pressure die all the blocks. By using such process, the consistent dimensional accuracy at such volume is easily achievable.
(Ford Motor Company, 2018)

Manufacturing Process

The manufacturing process that Nemak use for the Sigma block is high pressure die casting (HPDC).

The process of high pressure die casting in its simplest form consists of molten material being injected into a mould and let to solidify.

Here is a simple example of a high pressure die cast.

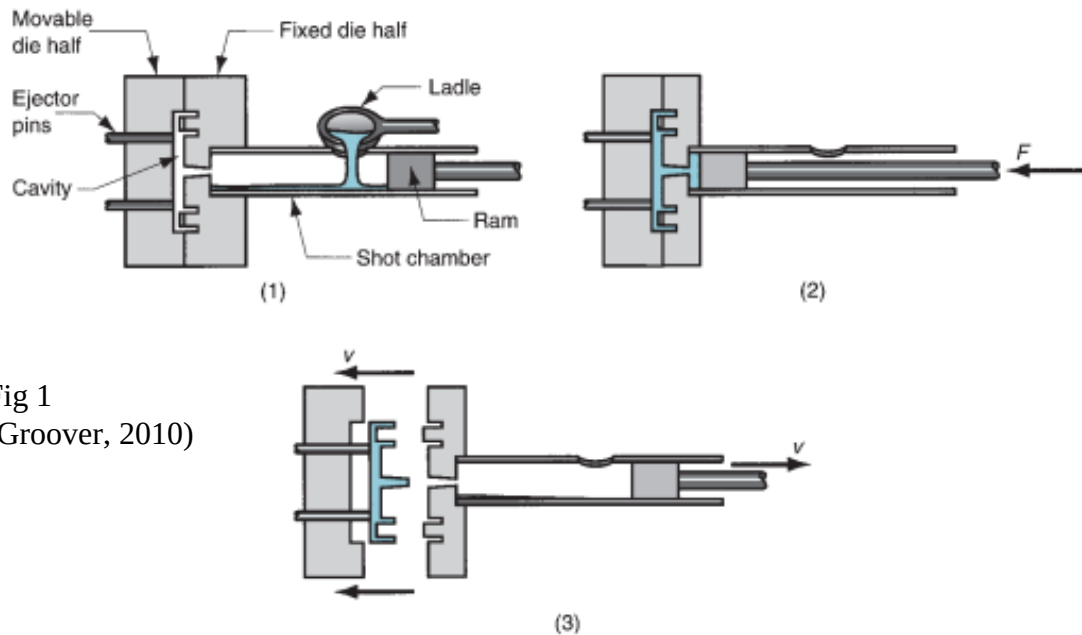


Fig 1
(Groover, 2010)

In example 1 molten material is poured into the shot chamber, the exact amount of material needed will be used. Firstly, it reduces waste second of all if the shot is too big it can cause quality issues such as flash. This form of HPDC is called cold chamber, this is for the reason that the chamber where the material is poured is not heated. The material comes from a heated container, and the shot is collected from the centre of the container to gain the best possible material. Once the shot chamber has the correct amount of material in the ram will force the material into the mould via the sprue. In example 2 is when the ram is fully extended, and the mould is full. The common pressure of a cold chamber is 14-140MPa (Groover, 2010). Once the material is in the cavity of the mould it then starts to solidify, the time of this process varies on the part and also the chemical structure required. Water gullies in the mould can decrease the cooling time greatly. Once the part has solidified then the part can be ejected and left to cool, also the time for cooling is part specific. After the part is ejected using ejecting pins, the mould will be cleaned and sprayed with a lubricant for the next part.

This process is commonly automated to increase productivity and reduce waste. Also, by automating the process it greatly reduces the risk of the health and safety of the workforce and the possible effect on environment. With having materials heated over 680°C it is very dangerous to have humans handling a ladle to pour into the shot chamber, this will be commonly done by a robot in an automated system. Once the part is completely solidified then the part may be handled by a human with the correct PPE or with a mechanic aid.

Advantages and Limitations of HPDC

Advantages of HPDC:

- High Production volumes are easily achievable
- Can be very economical in large quantities
- Close tolerances
- Thin sections are possible
- Controlled cooling
- Controllable surface finish
- Full Automated

(Groover, 2010)

Limitations of HPDC

- Part geometry must allow for part removal
- Weld lines must not be on critical geometry of features
- Wall thickness should be uniform
- Sharp corners and angles should be avoided
- Restricted to lower melting point material

(Groover, 2010)

Quality Concerns

As with manufacturing processes, HPDC has some quality concerns which must be taken into consideration when designing and manufacturing. Below are the following concerns and possible causes.

Short Shot – This is where material starts to solidify before filling the cavity fully. This could lead to having voids in the part or the material not fusing correctly. This can have a detrimental effect to the strength of the part and can cause serious failures. Possible causes are shot capacity too small, pressure/temperature too low.

Flash – Is when material is forced into the parting surface of the mould and will form a thin deposit of material. Common causes are vent holes too big, worn tool, injection pressure too high, clamping pressure is too high, melt temp too high and excessive shot. (Groover, 2010)

Sink Marks/Voids – This is common on non uniform wall thicknesses, the material on the outer of the wall solidifies before the centre this distorting the wall. The cause of this is just bad design.

Weld Lines – Is when material meets in the mould at different temperatures and does not fuse at intended. Causes of this is bad design or restriction in flow.

Porosity – Where gas bubbles are caught in melt and solidify inside the part. This causes defect in the part and will not perform as it should. Causes of porosity is turbulence in injection. Gases not being exhausted correctly.

Shrinkage – is where the material starts too cool and reduces in size. This is taken into consideration in design phase but still cannot be eliminated.

Meeting Manufactures Specification

Material Selection

As with most automotive engine components there are specific properties that are always considered when selecting a material. The properties are the material must be lightweight, strong and have good thermal properties all under normal engine operating temperatures. The most common material used in high volume manufacturing is aluminium.

Advantages of aluminium

- Aluminium has a third of the density of steel but does not affect its strength. (Sapa, 2018)
- Tensile strength up to 600MPa
- Easily Machined which reduced tooling and energy costs
- Corrosion resistant
- It is the 3rd most abundant element in the earth's crust and is fairly easy to mine and process.
- Low cost

Process Selection

Once the material selection has been carried out then the manufacturing process is chosen. When taking the specifications that Ford require, the manufacturing process does favour HPDC. If the material Ford required had a higher melting point than aluminium then other options such as the sand casting process should be considered. But as the specifications Ford set was the block must be made from aluminium, Nemak deem that HPDC is the best process to produce the Sigma engine. Nemak require high levels of control of the casting to ensure that they have a minimum level of waste and all aspects of the process can be controlled.

HPDC allows the control of the temperature and cooling of the tool, heat exchangers can either maintain temperatures or dissipate the heat for better cooling. When compared to sand casting where the heat is dissipated at the rate of the thermal conductivity and permeability of the sand. HPDC allows complete control and the ability to monitor temperatures.

One of the main advantages of HPDC is the dimensional accuracy, HPDC can have accuracy of 0.25mm whereas sand casting has an accuracy of 0.5mm. This level of accuracy is consistent even at high volumes. The accuracy is very important when the block come to the machining phase, where the dimensional accuracy of the datum's is critical. It enables machining machines to set depths of cuts and allows for off sets. The Sigma block has 3 datum's so it is critical that the block has overall dimensional accuracy. (Nemak, 2018)

Quality Issues

There are many quality issues that occur in the HPDC process. Most defects are caught at the foundry such as flash, weld lines and shrinkage. These quality concerns are dealt with then, and will be recycled. The most common quality failures that Ford have from Nemak is porosity and shrinkage. Due to porosity being gas bubble solidified inside the part it is very difficult to pick up, unless the use of ultrasound or x-ray is used. Nemak have optimised the process to greatly reduce porosity but it cannot guarantee 100% elimination of porosity. Only until the blocks are shipped to Ford and the machining process begins porosity is found. There are a number of areas on the block that porosity is commonly found. Fig 2 is the quality grid sheet of the Sigma 1.6 GTDI block.

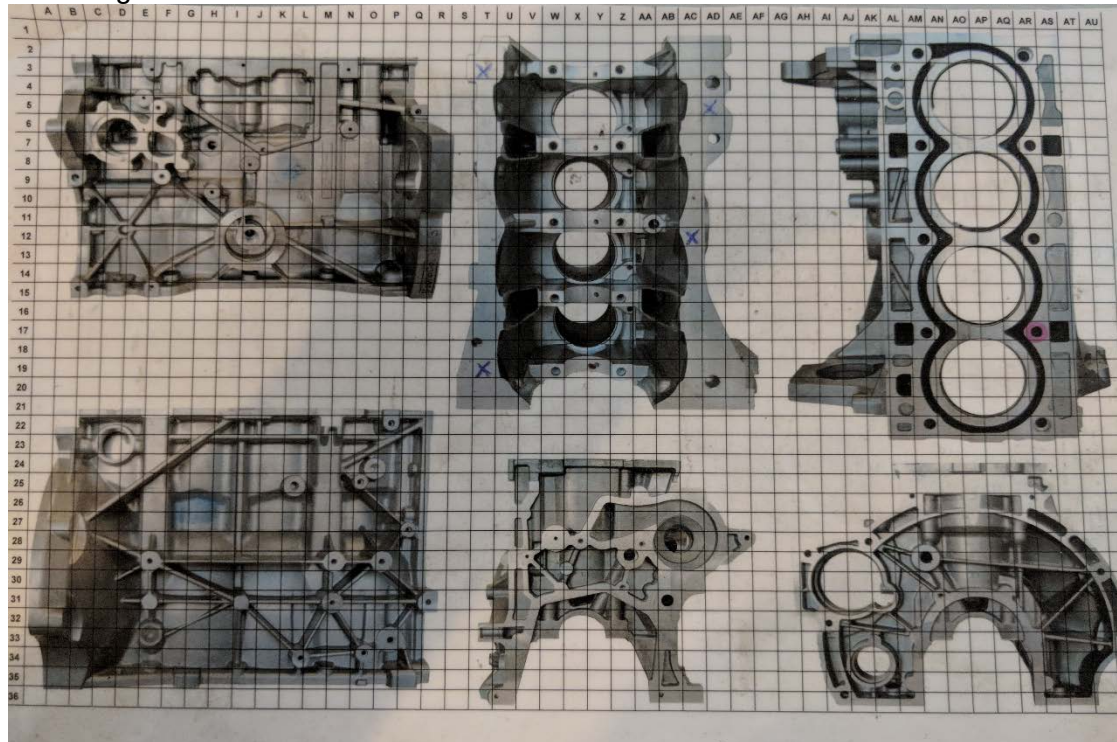


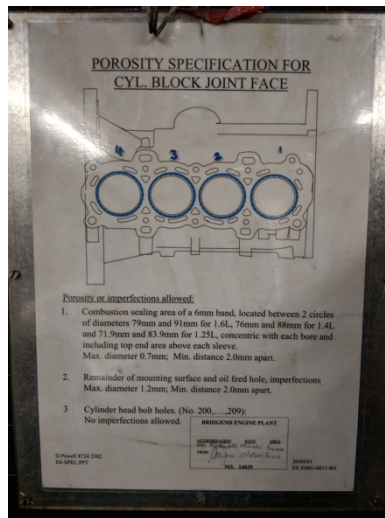
Fig 2
(Nemak, 2018)

Ford have accepted that there is a chance of porosity so a 100% check of all machined blocks are carried out. In Fig 2 there are some key areas that porosity occurs on the sump face these are grid reference T3, T18, AD5, AC12. If the porosity is within repairable specification, then it can be repaired by cold welding using Pattex Nural 21. If, however the porosity is on the head face then the block must be scrapped and recycled. By having porosity so close to the chamber where the temperatures are between 71°C – 110°C Ford cannot guarantee the blocks performance, so it must be scrapped.

Example of Quality Issue

Below is a 1.6 GTDi block with a shrinkage failure which was found in the 100% check at op150. The failure is highlighted with paint pen and stored in a failure rack.

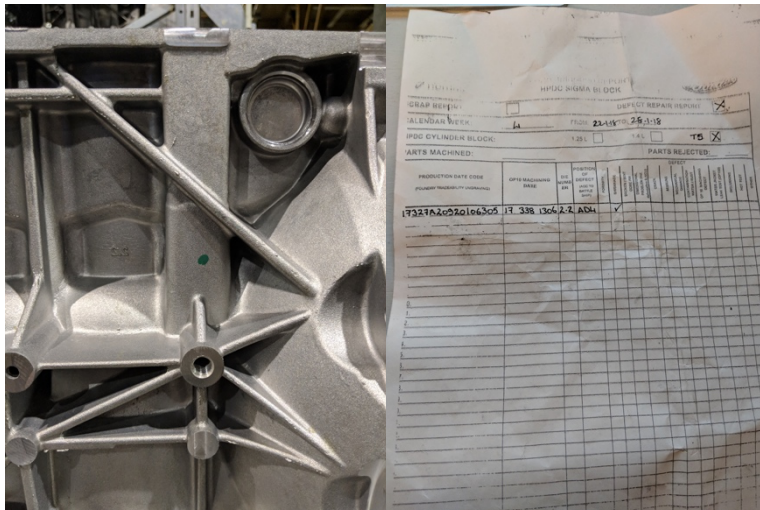
The fault is then distinguished, and cross referenced against the repair process sheet below. If the fault can be repaired, then it will be done using the Nural 21.



The blocks ID number, birth date and mould number are logged. If there is any pattern in the blocks or batch failures, then it can all be traced back and dealt with



Once the repair has been made a paint dot is placed on the block. This is so operators are aware that this block has been repaired and check thoroughly once passing through hot test.



(FoMoCo, 2018)

Summary

To summaries after some research into the production of the Sigma GTDi block. It was apparent that NemaK have nearly perfected the HPDC process, the volumes that they are achieving with very little failures is impressive. It seems that Ford and NemaK have optimised the material and design as much as possible which is as expected. NemaK and Fords will use all the technology and data from Sigma for the new Dragon engine, which will be in higher volumes in multiple locations around Europe.

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Credibility of Sources

All the research conducted in regard to Ford and Nemak was from company documents. For this reason, it would be fair to say that these sources are very reliable, and the data is the most up to date form.

The three books cited are also very reliable due to the authors being very credible and have outstanding experience in the industry.

The websites cited have no credibility except their reputation, the financial times article could be misinformed information. Also, the Sapa aluminium properties was checked against many other sources to ensure the information was correct.