ABSTRACT

Turbine hubs for automatic transmission torque converters are ideal candidates for the powder metallurgy (P/M) process. The complex shape of turbine hubs is costly to produce via conventional forging and machining operations. Increases in engine size and torque requirements by automotive designers require turbine hubs to possess high levels of mechanical properties. High density P/M manufacturing techniques, in combination with high performance ferrous material produces components capable of replacing a forged and machined turbine hub.

This paper will review the conversion of a conventionally forged and machined turbine hub used in a high torque automatic transmission to a single pressed and single sintered P/M turbine hub. The material used for the P/M hub was an MPIF FD-0405. Warm compaction processing achieved significantly increased overall sintered densities in the highly stressed internal spline region. Extensive mechanical and part specific testing was conducted to verify the suitability of the P/M part.

INTRODUCTION

The use of Powder Metallurgy (P/M) components has grown at a rate of approximately 7% annually since 1990. During this period, the usage of P/M components in the North American auto sector increased from 23 pounds per vehicle to in excess of 28 pounds per vehicle. Notable recent applications include connecting rods powder forged to near pore-free density, and P/M main bearing end caps that are pressed and sintered to a nominal density of 6.9 g/cm$^2$. It was proposed that the usage of P/M parts per vehicle could reach 50 pounds by the year 2000. These additional opportunities for P/M can be realized provided that the P/M process is capable of producing higher performance components at lower cost. Traditional methods to improve the mechanical properties of P/M parts include restriking, copper infiltration, or high temperature sintering to achieve the higher density and the corresponding higher mechanical properties. However, these methods are costly to implement thus slowing the growth of P/M within the automotive sector.

The recent introduction of the warm compaction technology enables P/M part fabricators to single press and single sinter multi-level complex P/M parts to densities in excess of 7.25 g/cm$^3$. Warm compaction processing, although applicable to all ferrous material systems, produces the greatest benefits when coupled with high performance ferrous alloy compositions. Achieving densities in excess of 7.25 g/cm$^3$ using diffusion alloyed materials and molybdenum prealloyed steels result in mechanical properties that are comparable to steel forgings and ductile iron castings. This paper will discuss the conversion of a forged steel turbine hub (using AISI 1045 steel) to a warm compacted single press single sinter P/M component. The complex shape of the component precluded the option of double pressing double sintering (DP/DS), and copper infiltration proved unacceptable.
WROUGHT TURBINE HUB PROCESSING AND THE WARM COMPACTION PROCESS

Turbine hubs in automatic transmissions are torque carrying components that have both internal and external splines with a provision for riveting. Their function is to transmit torque from the riveted turbine assembly to the splined transmission input shaft.\(^5\)

Powder metallurgy first was used in the manufacture of turbine hubs in the early 1960's. The original P/M turbine hubs were compacted to a 6.2 g/cm\(^3\) density and subsequently copper infiltrated for higher strength (Figure 1 is a photograph of this early P/M part). As a result of this early pioneering effort, nearly all current automatic transmissions now utilize P/M turbine hubs. The most commonly specified material is an MPIF FC-0208, which is a premix of pure iron powder with approximately 2\(\%\) (weight percent) copper, 0.8\(\%\) graphite plus lubricant.\(^6\) These current turbine hubs are processed to a nominal sintered density of 6.8 to 7.0 g/cm\(^3\) with sectional densities varying from 6.6 g/cm\(^3\) to 7.1 g/cm\(^3\).

Prior to production part approval, the warm compacted turbine hubs were subjected to extensive mechanical property evaluation. Standard MPIF tensile and fatigue testing was performed. Preproduction hubs were evaluated for internal spline durability and internal spline wear relative to both conventionally compacted P/M hubs and the forged hubs. This investigation was done in an MTS test cell designed specifically for torque testing. The test procedure consisted of fixturing the consumer demand for higher performance engines in the light truck and van market segments resulted in the development of new engines with higher torque for greater towing capabilities. One consequence of this higher engine output was the performance demands exceeded the torque carrying capability of conventionally pressed and sintered turbine hubs. To guarantee system reliability, the transmission designer was forced to switch from conventional P/M to alternative technologies to meet performance demands. Steel forging was one alternative chosen. The complex shape of the turbine hubs processed by the forging and machining process proved to be a costly option. What was needed was a high performance P/M material process that would survive the higher torque output of the new engines.

Figure 1: Early P/M Turbine Hub

Figure 2 shows schematically the manufacturing sequence of the wrought turbine hub. AISI 1045 bar stock is hot upset forged to form the flange and top cone. After forging, the blank undergoes approximately 8 distinct machining operations including turning and broaching of the outer (OD) and inner diameters (ID) and facing of the flange. The final step is induction hardening of the ID spline for strength and wear resistance. Figure 3 shows the forged and machined turbine hub.

Also shown in Figure 2 is the manufacturing sequence for the warm compacted P/M component. The powder specified was an MPIF FD-0405. This material is a diffusion alloyed powder containing 4\(\%\) nickel, 1.5\(\%\) copper and 0.5\(\%\) molybdenum.\(^6\) This base iron was premixed with graphite and lubricant; premixing accomplished by the ANCORDENSE\(^\text{TM}\) premix technology. The press-ready powder and compaction tooling were heated to the required temperatures utilizing a Cincinnati Incorporated El-Temp\(^\text{TM}\) material delivery system.\(^7\) Temperature control of the die and heated powder was maintained within +/- 2.5\(^\circ\)C of the set point. Compaction was done in an 825 ton Cincinnati Rigid Reflex press. The turbine hubs weighed approximately 1100 grams each. Following compaction, sintering was done at conventional temperatures using an endothermic protective atmosphere.

Figure 2: Schematic Manufacturing Sequence for Wrought and Warm Compact Turbine Hubs
Figure 2: Manufacturing steps of the forged steel turbine hub and the warm compacted turbine hub

Figure 3 Forged and Machined Turbine Hub

Table 1 summarizes the tensile properties, hardness values, and rotating bending fatigue characteristics of both the forged AISI 1045 and warm compacted MPIF FD-0405 materials. Data for the
forged AISI 1045 material is presented in the annealed and hardened condition (the ID is induction hardened). Property data for the FD-0405 is presented in the as-sintered condition at a density of 7.25 g/cm³ (the overall density of the warm compacted and sintered turbine hub). Data for the P/M material is presented in the as-sintered condition only because it was determined that no surface hardening of the ID was necessary.

The as-sintered yield and tensile strengths of the MPIF FD-0405 material were equivalent to the forged AISI 1045 steel. Ductility of the steel forging was higher than the warm compacted P/M part. The fatigue properties developed by rotating bending fatigue testing demonstrated that the steel forging in the as-forged condition had a higher fatigue endurance limit relative to the as-sintered warm compacted P/M part. Specific part testing was necessary to determine if the difference in rotating bending fatigue performance was detrimental to actual component performance.

Table 2 presents the internal spline durability test results of conventionally compacted turbine hubs, forged turbine hubs, and the warm compacted MPIF FD-0405 hubs. Production part validation required that 12 hubs be tested to 1 million cycles with no failures with one additional hub tested to 2 million cycles with no failure. This high torque regime of 0-890-0 foot pounds exceeded the strength capability of the standard FC-0208 material. Failures were observed below the specified minimum value. The forged turbine hub met the test requirements with no evidence of failures. Warm compaction of the turbine hubs produced parts having an overall sintered density of 7.25 g/cm³. Despite the lack of full density, the warm compaction process produced torque test results that exceeded the minimum specification requirements. That is, twelve hubs were subjected to 1 million cycles with no failures and 1 hub was tested to two million cycles with no failure. To evaluate the durability of the high performance P/M hub, one was cycled to failure. Structural failure of the hub occurred at approximately

<table>
<thead>
<tr>
<th>Property</th>
<th>Forged AISI 1045</th>
<th>Heat Treated AISI 1045</th>
<th>As Sintered MPIF FD-0405 @ 7.25 g/cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield Strength, psi</td>
<td>62,000</td>
<td>96,000</td>
<td>62,000</td>
</tr>
<tr>
<td>Tensile Strength, psi</td>
<td>90,000</td>
<td>130,000</td>
<td>117,000</td>
</tr>
<tr>
<td>Elongation, %</td>
<td>25</td>
<td>16</td>
<td>2.6</td>
</tr>
<tr>
<td>HRC/B</td>
<td>97 HRB</td>
<td>43 HRC</td>
<td>17 HRC *</td>
</tr>
<tr>
<td>Fatigue Limit, psi</td>
<td>45,000</td>
<td>100,000</td>
<td>35,000</td>
</tr>
</tbody>
</table>

* Apparent

Table 2: ID Spline Durability Test Results

<table>
<thead>
<tr>
<th></th>
<th>1 million cycles at 890 ft.lbf.</th>
<th>2 million cycles at 890 ft.lbf.</th>
<th>Cycles to Failure at 890 ft.lbf.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard P/M hub</td>
<td>Failures observed</td>
<td>Failures observed</td>
<td></td>
</tr>
<tr>
<td>AISI 1045 hub</td>
<td>12 parts, no Failures</td>
<td>1 part, no failure</td>
<td></td>
</tr>
<tr>
<td>Warm compact FD-0405</td>
<td>12 parts, no Failures</td>
<td>1 part, no failure</td>
<td>~9,000,000</td>
</tr>
<tr>
<td>Specification</td>
<td>12 parts, no Failure</td>
<td>1 part, no failure</td>
<td></td>
</tr>
</tbody>
</table>
9 million cycles, significantly in excess of the specified minimum. Spline durability testing of the high performance P/M turbine hub demonstrated that this process is capable of replacing a steel forging in this critical high torque application.

The second critical performance criterion of the turbine hub was internal spline wear. As described earlier, the analysis of the spline wear was performed in the same test cell as the spline durability evaluation. Table 3 summarizes the wear test results presented as relative measurements. That is, the maximum wear allowed by the specification is equated to 1. Any wear number less than 1 implies the wear was less than the specified maximum, thus meeting the specification. Any number greater than 1 implies the wear exceeded the specification, thus not meeting the specification.

Table 3: Summary of ID Spline Wear Tests

<table>
<thead>
<tr>
<th>Process</th>
<th>Wear after 350,000 cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard P/M hub</td>
<td>1.4</td>
</tr>
<tr>
<td>Forged and hardened AISI 1045</td>
<td>0</td>
</tr>
<tr>
<td>hub</td>
<td></td>
</tr>
<tr>
<td>Warm compacted FD-0405</td>
<td>0</td>
</tr>
<tr>
<td>Specification</td>
<td>1</td>
</tr>
</tbody>
</table>

Conventionally compacted and sintered FC-0208 turbine hubs were evaluated. These hubs exhibited excessive wear in this high torque application with a relative wear value of 1.4. Wear measurements of the forged hub showed no wear at the specified number of cycles. However, it is noted that the ID spline of the AISI 1045 hub was induction hardened to a hardness value 40 HRC. Without this hardening operation, the forged steel turbine hubs would not meet the specified minimum wear performance. Wear testing of the warm compacted MPIF FD-0405 showed no measurable wear at the specified number of test cycles. The absence of wear in the warm compacted turbine hubs is significant because these components were evaluated in the as-sintered condition. The apparent hardness of the P/M components was approximately 15 HRC. The warm compaction P/M process coupled with the MPIF FD-0405 high performance material system eliminated the need for heat treating of the internal spline thus significantly reducing manufacturing cost and simplifying the manufacturing flow.

Figure 4 is a photomicrograph of the as-sintered microstructure of the warm compacted turbine hub. It consists of lamellar pearlite, bainite, nickel rich martensite areas, and ferrite. This unique microstructure was responsible for the excellent wear performance demonstrated in the as-sintered condition.
As mentioned earlier, the overall sintered density of the turbine hub was 7.25 g/cm³. To achieve this high sintered density, the green compact was compacted to approximately 97% of the pore free density of the premix. One benefit of compaction to this high green density is the greater uniformity of density throughout the finished part. To document this, a production processed hub was sectioned and examined for porosity distribution along the length of the spline using quantitative image analysis. Figure 5 is a plot showing this density profile for a production part. The drop off in density in the small neutral zone is approximately 0.15 g/cm³ compared with the average sectional density of about 7.3 g/cm³. This reduced density differential is a significant improvement relative to the results achieved with conventional compaction in which this density differential can be as great as 0.4 g/cm³.

In addition to the mechanical property testing, extensive dimensional and weight capability studies were performed on the process. The results indicated that the variations measured were consistent with the variations obtained in conventional P/M processing.

**SUMMARY**

Warm compaction of an 1100 gram multi-level P/M turbine hub produced an overall as-sintered density of approximately 7.25 g/cm³. High densities were achieved in the critically stressed ID regions of the part. Combining the benefits of the warm compaction technology with a high performance material system, the need for induction hardening of the ID spline was eliminated. This resulted in a simplified manufacturing process and an overall part cost reduction. Extensive preproduction trials demonstrated that the warm compaction process is a viable manufacturing alternative for the production of complex multi-level shapes, in particular automatic transmission turbine hubs for high torque engines. This paper described the conversion of a forged hub to one produced via this high performance P/M material processing system. Torque testing of preproduction hubs demonstrated equivalent performance to the wrought component in terms of both ID spline durability and ID spline wear.
CONCLUSIONS

1.) Warm compaction processing of a complex multi-level turbine hub produced an overall sintered density of 7.25 g/cm³ with high sintered densities achieved in the critical ID spline region.

2.) Warm compaction processing of a high torque automatic transmission turbine hub successfully replaced a forged, machined, and heat treated AISI 1045 steel part. The P/M process significantly reduced the processing steps. The reduced number of processing steps resulted in overall lower manufacturing cost.

3.) Utilizing an MPIF FD-0405 material composition, the P/M turbine hub was used in the as-sintered condition eliminating the requirement for induction hardening of the ID spline as required in the forged component it replaced.

4.) Standard tensile and fatigue testing of the P/M material demonstrated that the P/M component was equivalent in yield and tensile properties to the wrought steel. The P/M part had a lower rotating bending fatigue strength.

5.) ID spline durability and ID spline wear testing of the warm compacted P/M component met and surpassed the requirements specified by the end user.

6.) Manufacturing variability of the warm compaction process was equivalent to the variability of the conventional compaction processes.

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REFERENCES


