

Single Press to Full Density for Automotive Powertrain Components: Gears and Sprockets

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ABSTRACT

The PM Industry Roadmap prepared in 2001 identified six top-priority research needs for the industry, including one entitled “develop material and processing technologies to achieve 100% density while maintaining dimensional tolerances and cost-effectiveness”. The Center for Powder Metallurgy Technology (CPMT) recognized this need as its top priority and put together a task force to establish a multi-year program plan to meet this need. Additional targeted funds were solicited to help offset the added costs of this major project, including the hiring of a special project leader. A two phased program was developed with the first target a 7.5+ g/cc density for structural steels through single press-single sinter processing and then a “stretch” target for Phase 2 of 7.7+ g/cc density. The four tasks identified for the Phase 1 program are described including the advanced technologies being investigated, the materials, equipment and processes used and the outcomes to be measured. A progress report update will identify the accomplishments to date, the problems encountered and the options yet to be investigated.

INTRODUCTION

The Center for Powder Metallurgy Technology (CPMT) is a not-for-profit organization established to serve the R&D needs of the powder metallurgy industry. Membership is open to all constituencies of the PM industry – parts makers, powder suppliers, equipment manufacturers, end users, consultants and academe. Current membership is approaching 50 companies and includes GM Powertrain, Ford and Chrysler plus Eaton Corporation, John Deere and Timken Corporation. The membership provides suggestions for new programs, votes on the program priorities, volunteers to participate on individual programs through established task forces and provides goods and/or services as needed to complete the programs. In some cases the programs are located at various members’ sites, while others are conducted at independent research institutions, university locations or testing laboratories.

For the past five years CPMT has taken direction from its member companies to pursue programs that support the development of high performance PM sprockets and gears for automotive engines and transmissions. Several industry market studies have shown these two product classes represent a potential market that approaches the size of the entire automotive PM parts market in North America today. The major technical issues facing PM gears/sprockets are contact fatigue, bending fatigue and wear. The Center has completed major gear-themed programs on rolling contact fatigue and single tooth bending fatigue [1, 2] as well as a related program on the machinability of PM steels. Current projects related to improving PM gears and sprockets but not the subject of this report include low cycle fatigue testing, net shape specimen fatigue testing and lubrication for compaction.

BACKGROUND

The MPIF sponsored PM industry Vision and Technology Roadmap was prepared in 2001 under the guidance and support of the Department of Energy. In that document (available on the MPIF website, www.mpiif.org) six top priority research needs were identified, including research need #2 “develop material and process technologies to achieve 100% density while maintaining dimensional tolerances and cost-effectiveness”. As most industry experts are aware this is no simple task. The compressibility of the base iron or steel powder, the need for low density admixed additions such as graphite and lubricant and the ability of the tooling to withstand ultra high compaction pressures all place a seemingly insurmountable upper limit on the compaction of engineered, structural steel powders.

A series of program development steps were undertaken to advance toward this ultimate goal. In 2002 a DOE-OIT proposal was prepared in conjunction with the DOE lab at Oak Ridge, TN (ORNL). With very little previous experience in preparing such a proposal we were unsuccessful in being granted a funded program.

Nevertheless the CPMT Board suggested the program not be quashed but rather consider other alternatives. In 2004 we completed an internal feasibility study and recognized that attempting to complete this monumental task with our limited CPMT funding stream would take an incredibly long period, perhaps as long as 10 years. Recognizing the industry need could not wait 10 years an internal champion rose to the occasion and suggested we raise targeted funds just for this project. Five CPMT companies responded to the request and we were able to raise over \$50,000 per year for a three year period to initiate this program. In addition a special program leader was named to spearhead the project. In 2006 the program, identified as the Single Press to Full Density (SPFD) program was launched.

PROGRAM GOALS & TASKS

The Phase I goal was to achieve a 7.5+ g/cc density using commercial, state-of-the-art materials and processes without compromising dimensional control or cost effective processing. The program was designed to use as many CPMT members, their products and processes as possible in order to objectively evaluate the current state-of-the-art. Well established gear/sprocket geometries would be used to determine the limits of the technologies. In all cases only one compaction and one sintering step would be used to create the test product.

The task force identified four program tasks for the Phase I program.

Task 1 – High Velocity Compaction (gear)

Task 2 – Traditional Warm Compaction (gear)

Task 3 – Effect of Part Length on Warm

Compaction (sprocket)

Task 4 – Ultra High Pressure Compaction

Each task will be described in order and the current status of activities reviewed.

TASK 1 -The High Velocity Compaction task utilizes the Hydropulsar press technology developed in Sweden [3]. The technology is based on a pulsed, high energy impact (20-300ms) from the press through the tooling adaptors and into the punch. This rapid impact is then transmitted to the powder causing a very rapid, high energy compaction cycle. The press has successfully produced single level steel parts in the 7.4-7.6 g/cc density range, using both conventional and warm pressing methods. The equipment is distributed in the USA by Gasbarre Products, a CPMT member company. For the purposes of this program the task team utilized the Hydropulsar press available at the Gasbarre location in DuBois, PA. The technical team consisted of experts from Hydropulsar (who traveled to the USA especially for the CPMT press run), Gasbarre Products, North American Hoganas, Burgess-Norton Manufacturing Company and NetShape Technologies (the only PM parts producer with an installed and operational Hydropulsar press in North America).

For the purpose of this study the task team selected the single level Gear Research Institute (GRI) test gear

geometry (3.00 inch PD, 24 teeth, 8 DP, 20° P.A., 0.500 inch thick), as shown in Figure 1. The tool steel, tooling and adaptors were donated and/or manufactured by CPMT member companies, following designs prepared by Hydropulsar. Three part thickness were attempted – the nominal 0.500 inch, 1.000 and 1.500 inches (aspect ratios of 2.2, 4.5 and 6.7). The test powder consisted of prealloyed steel powder with 0.85% molybdenum (FL-4400) with the addition of 1% Inco T110 nickel powder, 0.35% graphite and 0.5% lubricant. The calculated pore-free density for this powder is 7.52 g/cc. Using an estimate of attaining 99% of the pore-free density, the expected green density following HVC was 7.45 g/cc. Powder blends were prepared, using slightly different lubricant systems, for both conventional room temperature compaction and warm compaction.

Status - Gears have been successfully pressed using both conventional and warm compaction on the Hydropulsar press. The gears were then sintered with conventional and high temperature sintering cycles using production sintering furnaces. The gears are next scheduled for measurement of critical gear geometry features and statistical uniformity prior to heat treatment (case carburize). Following heat treatment the gear data will be re-measured prior to static and dynamic (fatigue) testing of the gear teeth.

TASK 2 -The traditional warm compaction task utilizes conventional mechanical press compaction equipment but relies on proprietary binder-lubricant systems developed by Hoeganaes Corporation (a CPMT member company) for the boost in densification [4]. The target green density for this task was 7.4+ g/cc, again using the same GRI test gear geometry as described previously (Figure1). The task team consisted of experts from Hoeganaes Corporation and Alpha Sintered Metals. Four different powder mixes were evaluated – two based on FL-4400 prealloyed powder (one with and one without admixed nickel) with 0.35% graphite and 0.3% of the Ancordense proprietary lubricant and two based on 0.30% molybdenum prealloyed powder (one with and without admixed nickel powder) with the same amount of graphite and lubricant as the previous two mixes. The estimated pore-free density for these powders was 7.6 g/cc; using a 98% of this value as the upper limit for compaction yields 7.45 g/cc. Both the powder and the die were heated for this study. The tooling consisted of a previously designed CPMT tool set that had been used for the Single Tooth Bending Fatigue test program, upgraded with a new lower punch (see Figure 2).

Status - Gears were successfully pressed using warm compaction conditions on a production mechanical press. The gears were then sintered with conventional and high temperature sintering cycles using production sintering furnaces. The gears were vacuum carburized using a 10 bar nitrogen quench and then tempered at 325°F for 2 hours. Next the gears will be measured for gear geometry features and statistical uniformity prior to static and dynamic testing of the gear teeth.

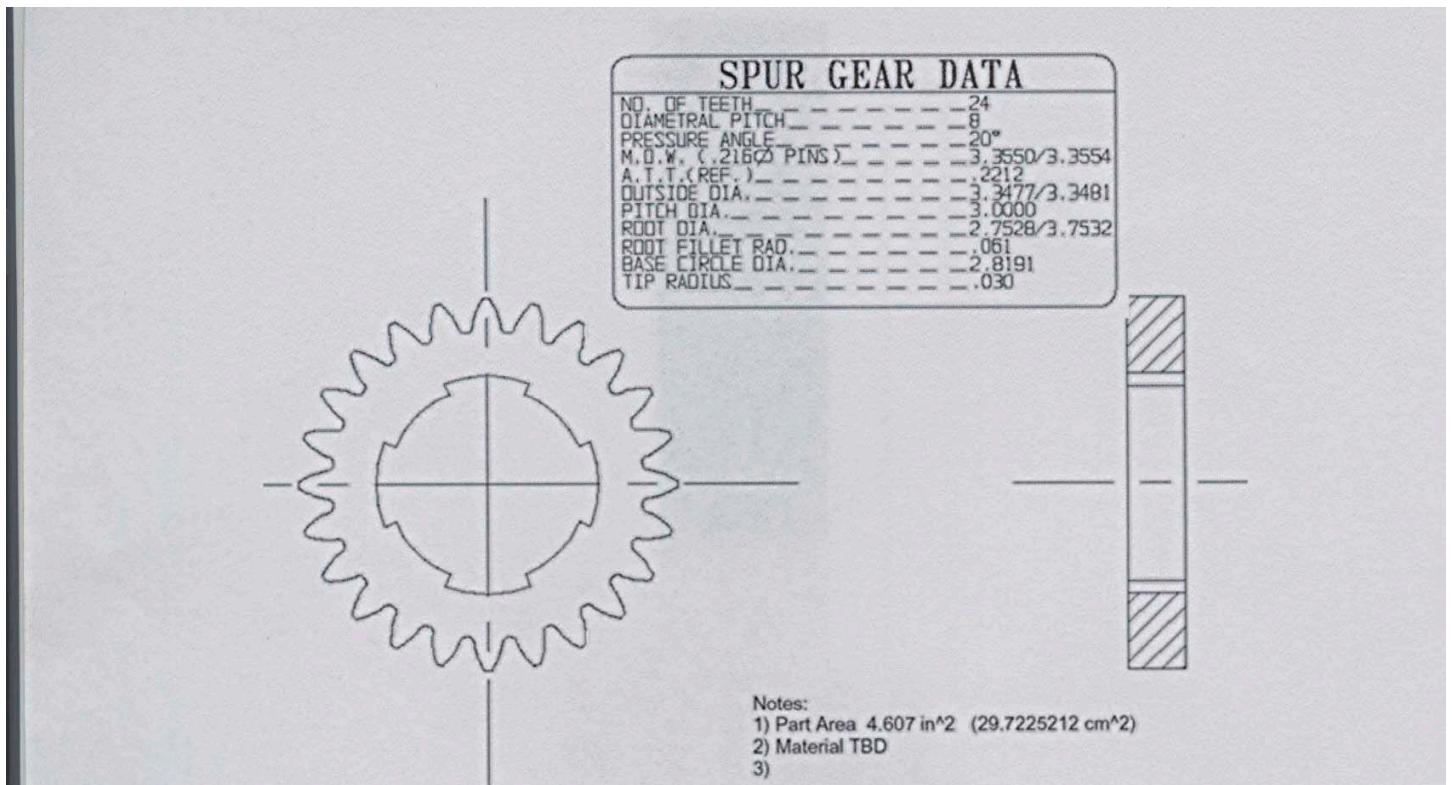


Figure 1. CPMT-GRI test gear used in the SPFD test program

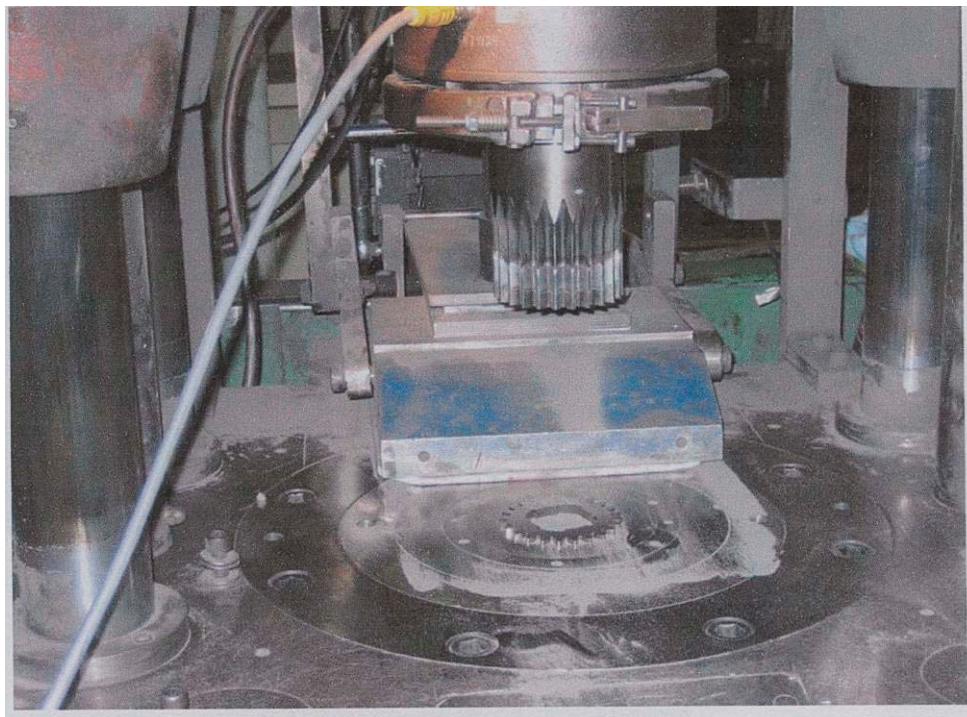


Figure 2. View of the tooling and feedshoe used to produce the warm compacted gears.