RECENT APPLICATIONS OF BINDER TREATMENT TECHNOLOGY

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ABSTRACT

The development of a practical binder treatment process in the late 1980's has since led to the commercialization of several new premix technologies that have had a major impact on P/M competitiveness. To date, a great deal has been written about these technologies. However, until now, there has been little to suggest that they are inherently interrelated by a common approach, or that this approach has untapped potential for still newer and better technologies. In addition, it also happens that in spite of all that has been written on the existing technologies, there is nothing that serves as a comprehensive single source of information on all of them. Consequently, the purpose of the present paper is to document the indicated approach as well as to present a summary description of each of the technologies complete with one or more production case histories of recent origin. The aim of the latter is to present discriminating up-to-date examples of general interest as well as to highlight one or more of the various advantages of the associated technology.

INTRODUCTION

The P/M industry has pursued many challenges over the last 15 years to make the technology more competitive with other metal forming and polymer technologies. Productivity, compressibility, scrap rates, tolerances, performance and environmental enhancements continue to be the focus of the industry's research and development community. It has been this dedication to challenging and reinventing P/M technology that has made the industry grow at a faster rate than any other metal forming endeavor.

Successful penetration into high volume critical automotive products has helped the industry to move quickly to develop the value image required to support further development opportunities. A uniquely close working relationship between the design and engineering teams of the powder manufacturer, the part fabricator and the end user has been the key to advancing the use of metal powders.

Many opportunities lie ahead for future growth in the usage of P/M technology in tomorrow's engineered products. High strength castings, precision gears, stainless steel exhaust components, and P/M connecting rods are achievable targets as new advances continue to overcome the challenges to P/M competitiveness.

One of the major technological avenues that has been providing answers to many of the questions these challenges raise is binder treatment processing. Accordingly, the development of practical methods to binder treat premixes combined with research leading to a better understanding of both lubricants and compaction has resulted in significant advances in P/M parts making capabilities within the last 10 years. The leading technologies incorporating these advances are commonly known to the industry under the trade names: ANCORBOND® ANCORDENSE®, and ANCORMlX™(Ancor®GS-6000)[l*]. All are patented products and/or processes of the Hoeganaes Corporation, [1, 2, 3].

These material processes and the resultant products were developed in an effort to provide solutions to customer identified weaknesses in the compaction system. The principal aim of the binder treatment process is to optimize the utilization of the typically fine admix ingredients by limiting their inherent dusting and segregation characteristics. In addition to alloy homogeneity, an equally important focus was to maximize the powder flow and die filling characteristics of the resultant mixes so as to provide better weight control and improved dimensional tolerances after both pressing and sintering. Improved compressibility, reduced ejection forces and improved productivity were also considered at various stages of the design process.

The research leading to binder treated materials employed an essentially cross disciplinary approach that included several different engineering branches. In particular, the practical solutions to developing this new technology were a result of applying the various methods and resources of the metallurgical, chemical process, and organic chemistry sciences. Binders, lubricants and traditional metal powders were combined with chemical, mechanical and thermal processes to produce systems capable of being utilized within the constraints of conventional P/M equipment and processing.

The combination of the cross disciplinary approach and the decisive parts-making success of the resulting technologies is considered to define what is in essence a new paradigm in premix research. Actually, the potential of the cross disciplinary approach was recognized as a rich new area of exploration early in the work that led to the ANCORBOND process. Virtually from the outset it was evident that many of the organic materials that were being investigated as binders were capable of producing effects other than simple bonding. Of course, during this early stage, many of the effects were modest and in a few cases, negative. Nevertheless, it was clear that given a better understanding of both the materials and their behavior, significant opportunities to develop new solutions to old problems existed. Subsequently, as this understanding grew, new insights into the basic mechanisms that affect virtually every premix property of interest as well as numerous new ideas for manipulating them to achieve the desired improvements arose. Eventually, as its turned out, the model of the premix that has evolved is one in which the organic additives and to a lesser extent the manner of their addition have come to be regarded as the principal determinants of the behavior of the resultant mix.

TECHNOLOGY REVIEW

In what follows, each of the three major technologies that have so far been derived from this paradigm are reviewed and recent case histories that are illustrative of each are presented. The latter include: five ANCORBOND, four ANCORDENSE, and one Ancor GS-6000 examples. Each was submitted in response to an open request to the P/M industry for contributions to this paper.

ANCORBOND TECHNOLOGY

ANCORBOND is basically a binder treatment technology that combines a purely chemical process step with traditional mixing to produce so-called bonded premixes. The chemical step mentioned involves solvent dispersal and evaporative deposition of one or more organic materials as bonding agents. The primary objective, of course, is to bond the ultra-fine alloy additives that are employed in premixing to the larger particles of the base powder. The ultimate aim being to limit demixing due to segregation and/or dusting during subsequent handling and part manufacturing.

The ANCORBOND process results in improvements in just about every parts production performance criterion of practical interest. The early development studies indicated exceptional improvements in flow and alloy dusting resistance as well as statistically significant improvements in weight control and dimensional stability. The significant effects of the treatment on powder flow, for example, are illustrated in Figure 1. Concurrent variability reductions in sintered mechanical properties indicated accompanying improvements in compositional homogeneity [4, 5, 6, 7]. Subsequently, experience derived during commercialization of the process not only confirmed these indications but showed that the superior flow characteristics and the inherent consistency of bonded mixes also gave rise to significant productivity improvements. These were manifested in several ways including principally increased pressing rates, decreased frequencies of press adjustments and decreased scrap rates [8].

Early limitations of bonded mixes compared with conventionally processed mixes included generally higher apparent densities and lower green densities at pressures in excess of about 40 tsi. Continuing improvements of the technology since its inception, however, have all but eliminated the apparent density differences and have completely reversed the situation on compressibility. Current bonded mixes still tend to exhibit slightly higher apparent densities than conventional mixes but can, if necessary for retrofit applications involving fixed fill dies, be made to essentially the same apparent densities [9]. More significantly, when compared with conventional mixes, current bonded mixes exhibit roughly equivalent compacted densities at low to moderate pressures and substantially increased densities at high pressures [10]. For example, depending on composition, density increases of up to 0.10 g/cm^3 are not uncommon at compaction pressures in the range of 40 to 50 tsi.

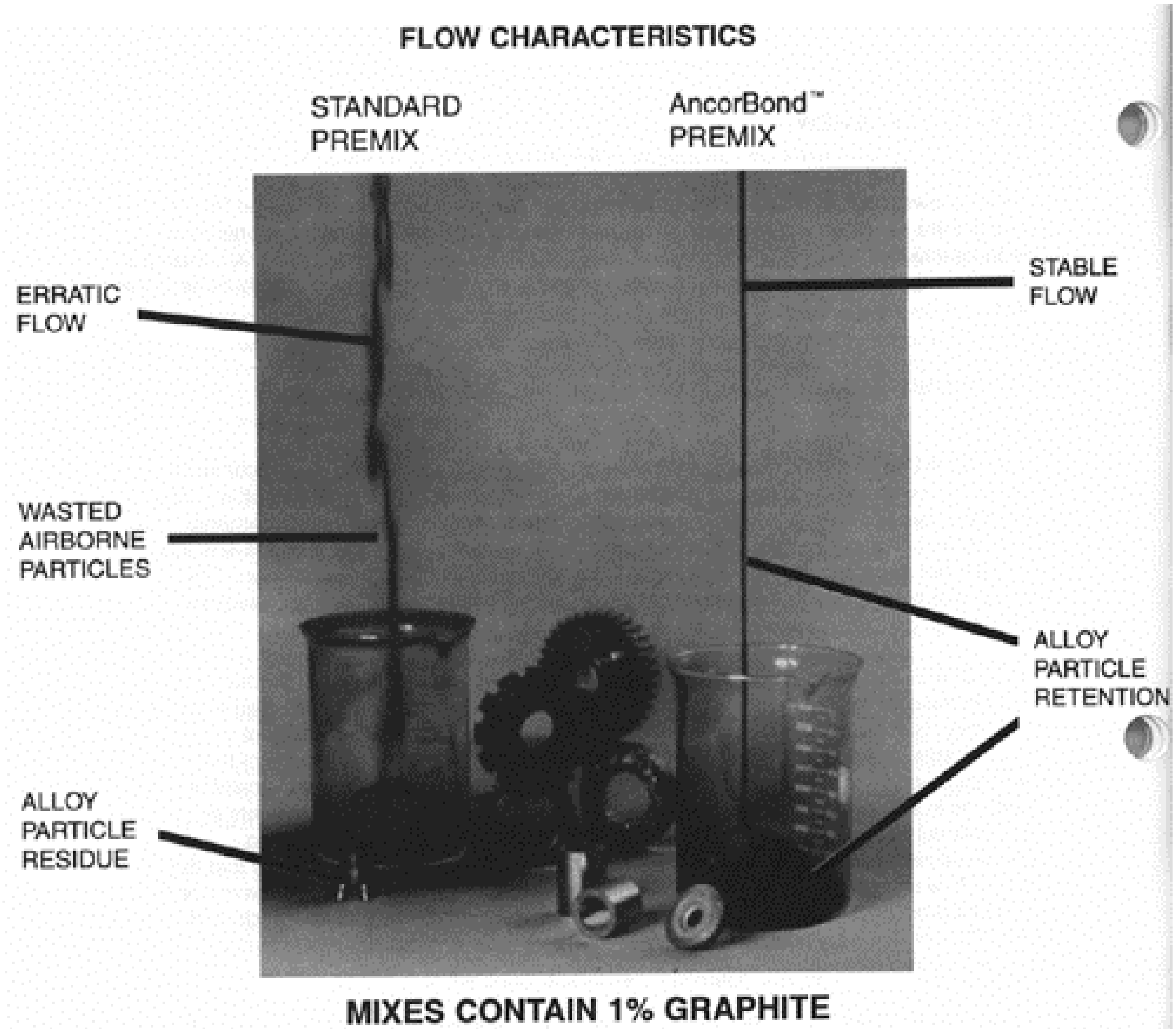


Figure 1: Flow/fill characteristics of conventional and ANCORBOND premixes. ANCORBOND processing improves flow rate, fill uniformity and reduces dusting/segregation.

Bonded mixes also have beneficial effects on working conditions and general plant cleanliness. This particular feature derives from their better dust resistance compared with conventionally processed mixes. Quantitatively, the dust resistance property measures the resistance that a mix offers to admixed alloy dusting losses when submitted to nitrogen elutriation under standard conditions of flow rate and time [4]. Qualitatively, it reflects the ability of the mix to resist dusting. In general, bonded mixes exhibit dust resistance values that are three to five times higher than those of conventionally processed mixes. Consequently, under actual parts making conditions, they effect substantial reductions in the airborne concentrations of respirable nuisance dusts [11]. This particular result is shown below in Figure 2 as reproduced from the original study. The result of these improvements is not only a better working environment but noticeably reduced housekeeping requirements as well.

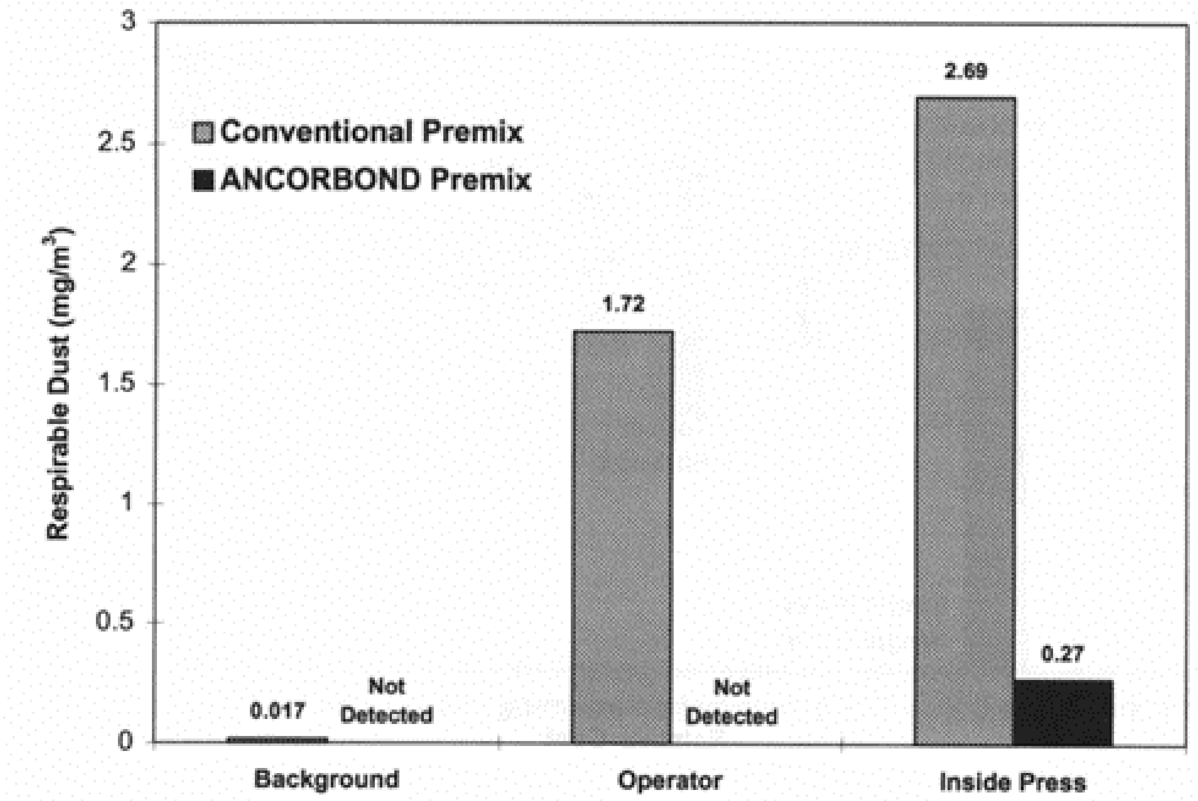


Figure 2: Respirable Dust In Work Area for a Conventional Premix and an ANCORBOND Premix.

ANCORDENSE TECHNOLOGY

ANCORDENSE or warm compaction technology, as it is otherwise known, permits the production of high density parts in a single compaction step [12,13,14 ,15]. Like ANCORBOND, this technology is the product of the convergence of basically differing disciplines. For example, it not only employs the same basic binder treatment processing as the latter but adds a special binder-lubricant system that was engineered on the basis of modern organic chemistry concepts to produce mixes that will provide enhanced performance at moderately elevated temperatures. The aim, in this case, being to take advantage of the significantly increased densities and/or lower compaction pressures that are attainable at such temperatures. Thus, as suggested at the outset, its use requires a warm compaction step that entails heating both the powder and the tools to temperatures in the range of 130° to 150°C (260° to 300°F).

Since almost all properties including strength and magnetic performance increase with increasing density, the ultimate aim of the technology is to provide a relatively economic means to produce parts with improved properties. Thus, the densities that are achieved rival those attainable with either the double press and double sinter (DPDS) or the copper infiltration methods but at substantial cost advantages as indicated in Figure 3, [12]. In addition, the technology offers significantly enhanced green strengths as well as many of the same parts making advantages of the ANCORBOND technology.

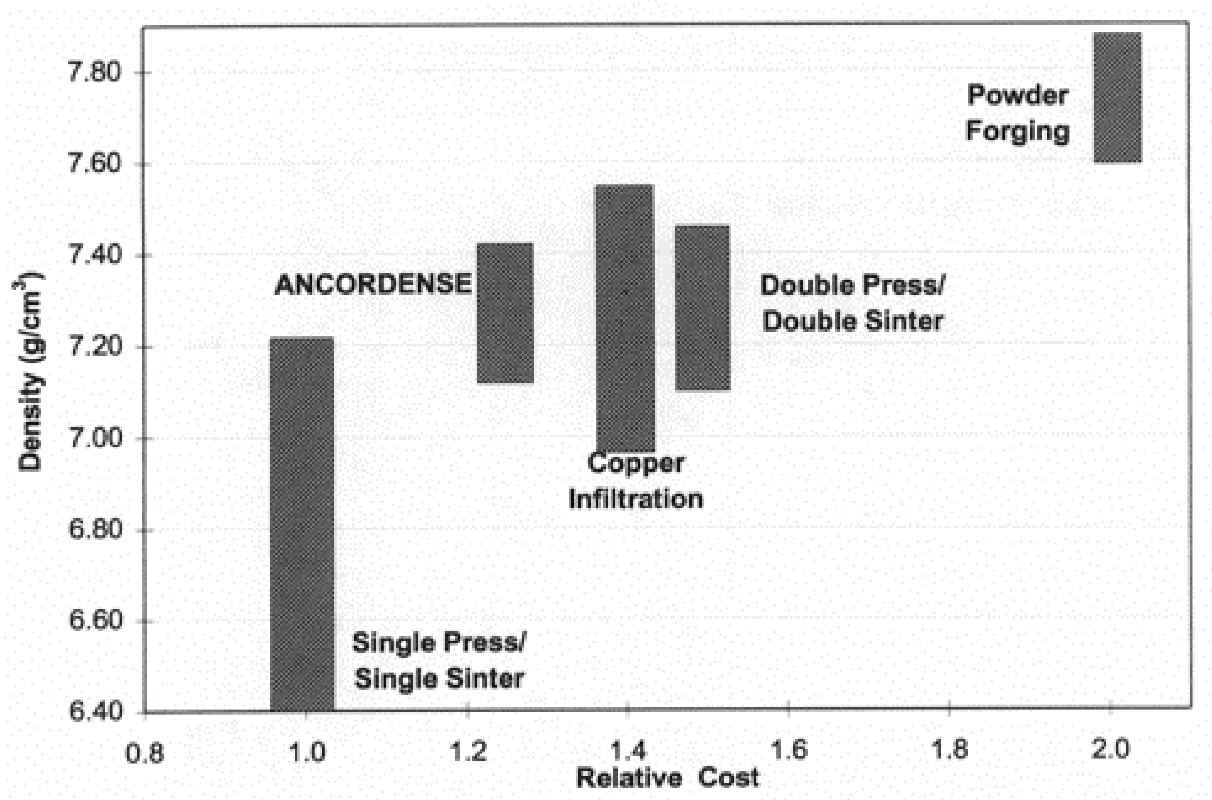


Figure 3: The Relative Cost And Density Ranges For Various Powder Metallurgy Processes.

The actual densities that are achieved with ANCORDENSE are strongly composition dependent but are typically in the DPDS range of 7.2 to 7.4 g/cm^3. Interestingly, when compared with DPDS, a particular advantage of the technology is the capability to produce highly complex parts which otherwise would not lend themselves to a second compaction step. On the other hand, there also is the possibility to combine the technology with DPDS aiming at densities in the 7.4 to 7.6 g/cm^3 range. The objective in this case, of course, is to compete for low end applications that are presently the province of an alternative technology such as forging or ductile iron casting, [16].

In addition to high density parts, the higher compressibility inherent in the technology offers other advantages as well. For example, when compared with ordinary compaction, the incremental density improvements with ANCORDENSE vary with density; the density improvement being about twice as great at low to intermediate densities as at high density. Thus, the possibility exists to increase press utilization by taking advantage of the technology to produce low to intermediate density parts using presses that could not otherwise be used due to tonnage limitations. Correspondingly, a related possibility is to use the technology to reduce both the wear and the risk of overloading with punches and/or core rods of high aspect ratio and/or with any tools that are generally of a delicate configuration.

The green strength enhancements mentioned in connection with the technology are, like the density improvements, composition dependent. However, as a general matter, the values that are observed are typically one and one half to two times greater than the values that are attainable with conventional mixes compacted to either the same pressures or where possible, to the same densities [12,17]. The primary advantage in this case is the possibility to employ green machining as a regular fabrication step. Although there is limited practical experience to date, laboratory studies have shown that drilling, turning and milling are all feasible [18,19]. Sintered control of the tolerances of machined features is comparable to that with the as-compacted ones.

Another advantage of the increased green strength is the likelihood of a lower incidence of pressing problems due to green cracking. However, it is extremely important to understand that of the several different types of green cracks that exist, there are some that the present green strength increases will not prevent. These are the cracks that are typically due to an adverse material flow during the compaction cycle or, more commonly, to over pressing.

Finally, superior dusting resistance and flow characteristics are the advantages that accrue to ANCORDENSE premixes as a result of the fact that they are bonded. The associated production rates, weight control, and dimensional stability also are comparable to conventional mixes.

ANCORMIX™ TECHNOLOGY

ANCORMIX is a new family of enhanced premixed materials designed to address very specific needs in the P/M process. Custom premixes containing Ancor GS-6000 are the first products to be produced in this family.

The Ancor GS-6000 technology is a premixing process that is based on a specially engineered surface treatment that imparts heretofore unparalleled improvements in green strength and die ejection forces as well as modest improvements in the compressibility of most ferrous materials [20]. At present, the technology is regarded as a specialty tool rather than a general purpose one. A primary consideration in this regard is that in addition to the benefits, its use normally entails sintered strength losses as well . Although these seldom exceed 10 percent and are often less, they are nevertheless a limiting aspect of the technology and consequently pose a natural impediment to its general applicability.

The actual green strengths that are attainable in a particular case are dependent, of course, on both the composition of the associated mix and the pressures and/or densities to which it is pressed. For the more common compositions, values of about 5000 psi can be expected at pressures of 30 tsi (i.e., at densities of ~6.8 g/cm^3), and still higher values, well in excess of 6000 psi, at pressures of 40 tsi and higher (i.e., at densities of ~7.0 g/cm^3 and up). In comparison, the green strengths of conventional mixes seldom exceed 3000 psi even at the very highest pressures and densities (e.g., at 50 tsi or ~7.2 g/cm^3). Thus, the technology is applicable to produce complex parts that are both green machinable and likely to exhibit a lower incidence of green cracks, especially as arise in subsequent handling. Unlike ANCORDENSE the technology does not require the warm compaction step that is essential to the latter. Once steady state pressing conditions are attained, ordinary compaction is all that is needed to provide the indicated improvements.

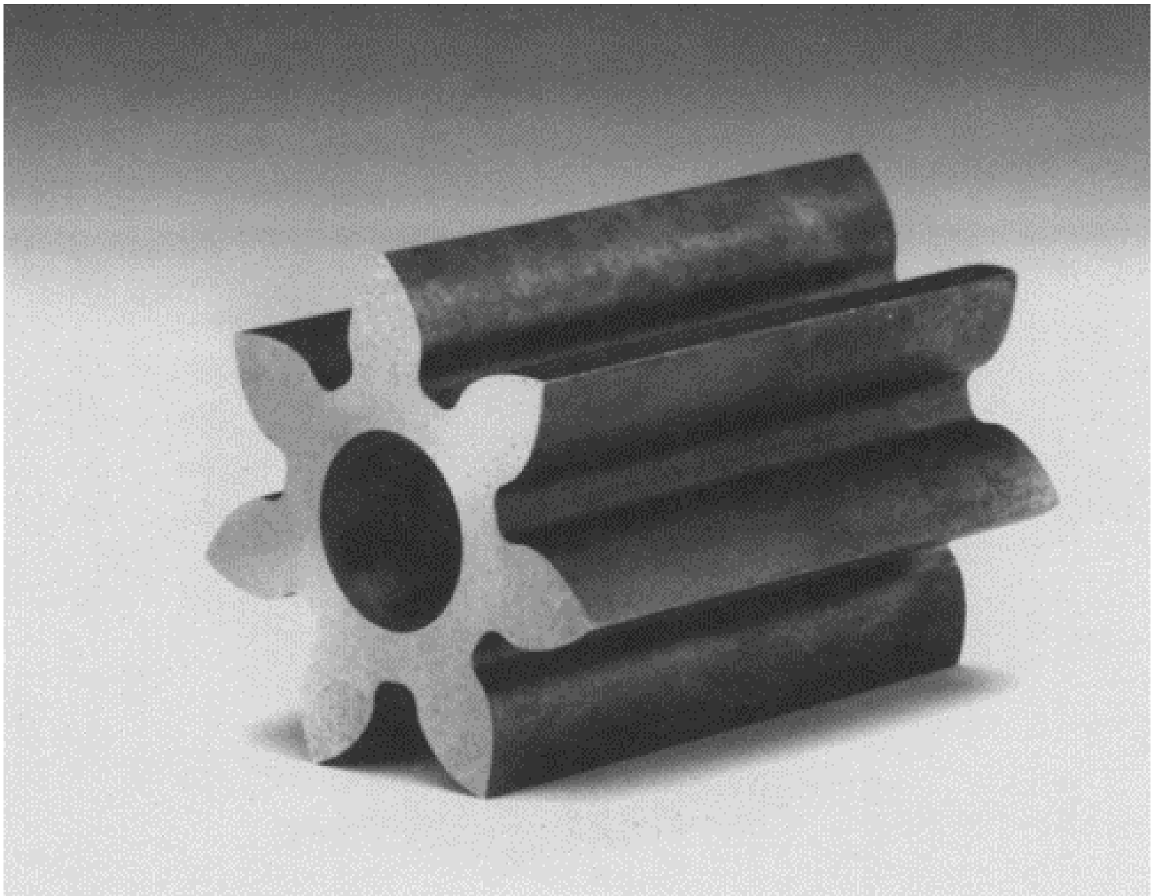
Compared with similarly processed conventional mixes, the compressibility improvements mentioned in connection with the Ancor GS-6000 technology tend to increase with increasing pressure or density. Interestingly, however, they do not appear to be very dependent on composition and they are, at best, fairly modest. For example, at the highest pressures and densities, they seldom exceed 0.05 g/cm^3 and are frequently less. In contrast, the relative improvements of the technology on the die ejection forces generally appear to be much more substantive. However, they are markedly more composition dependent. In particular, different compositions do not necessarily exhibit analogous trends with respect to changes in pressure and density. Thus, at best, the observed ejection force values with premixes made according to the technology are 25 to 35 % lower and, at worse, never greater than those of similarly processed conventional mixes of the same compositions.

Finally, analysis of the earlier mentioned sintered strength losses that arise with the technology strongly suggests not only the possibility to eliminate them but to replace them with modest improvements. Both of these findings, as well as others relative to the Ancor GS-6000 are the subject of a companion paper that is scheduled to be presented in the course of the present proceedings under the title, “Processing Experience Of Green Strength Enhanced Material Systems” [21].

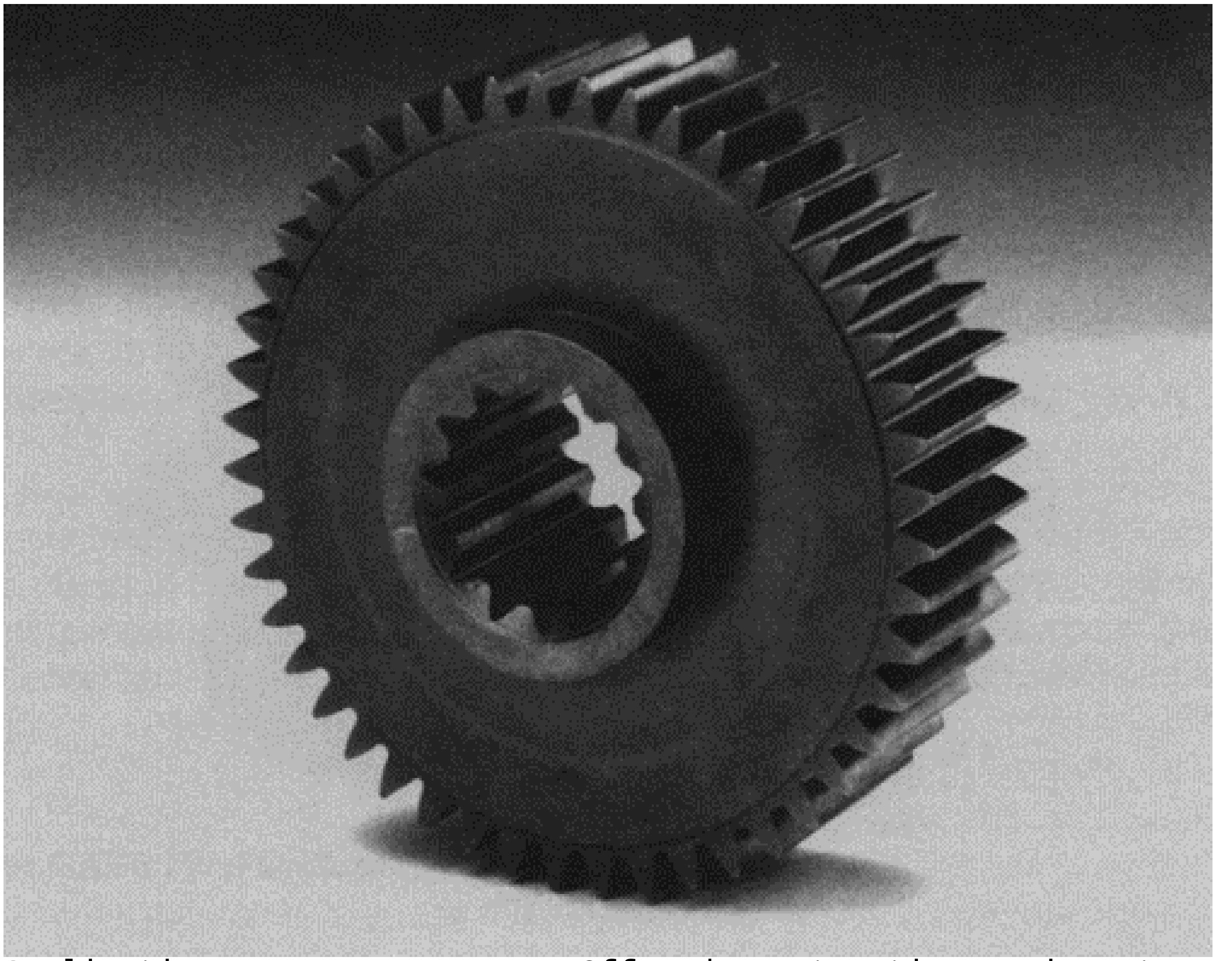
PRODUCTION CASE HISTORIES

The several case histories that were submitted in response to the aforementioned request to the P/M Industry follow. In addition to a general description of the part and its area of application, the reasons for specifying P/M and a surface treatment technology were also requested. The kind of details that were of interest were the relative improvements in such production qualities as costs, press speeds, compressibilities, scrap rates, green crack frequencies, press down times and/or the reduction of fabrication steps. As will be seen, each of the various respondents provided information on at least one of the indicated qualities and in a number of cases, in terms of two or more.

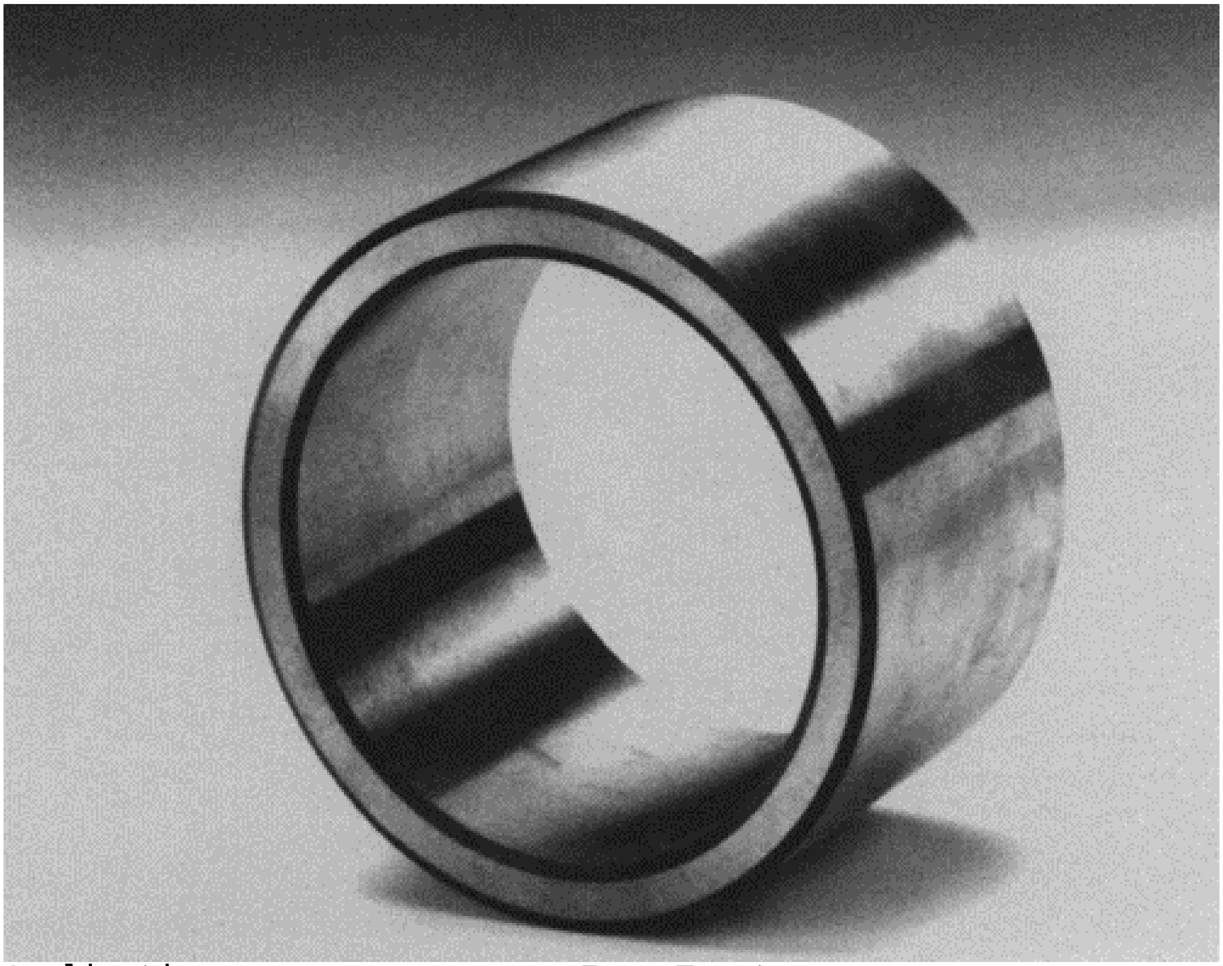
In some of the case histories, specific information has been withheld by request. Also, in some cases, certain data have either been withheld or are presented in relative rather than absolute terms to protect the proprietary nature of the associated applications. Lastly, in all cases, the kind of details that are presented necessarily vary in accordance with the manufacturing requirements of the associated part.



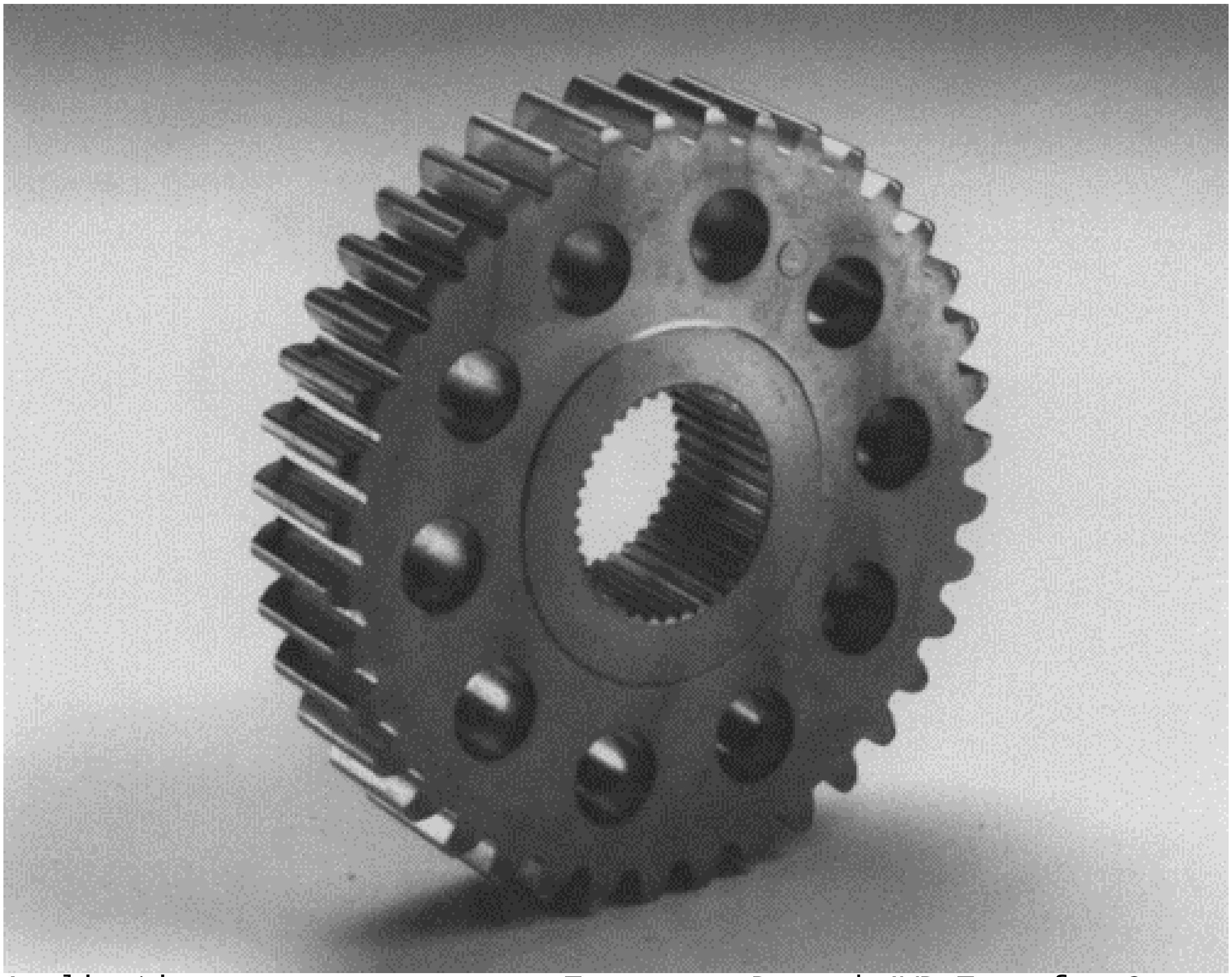
Application:	Farm equipment
Part Name:	Lubrication pump gear
Part Fabricator:	Burgess Norton Mfg. Co.
End User:	John Deere
Material:	FL-4605 heat treated
Density:	6.8 g/cm^3
P/M Application Benefits:	Cost Effective - Converted from wrought steel. Reduced the cost by 67% as a result of reduced machining requirements.
Binder Treatment Process:	ANCORBOND
Binder Treatment Benefits:	Made it possible for the part to be ejected. Improved the surface finish dramatically.



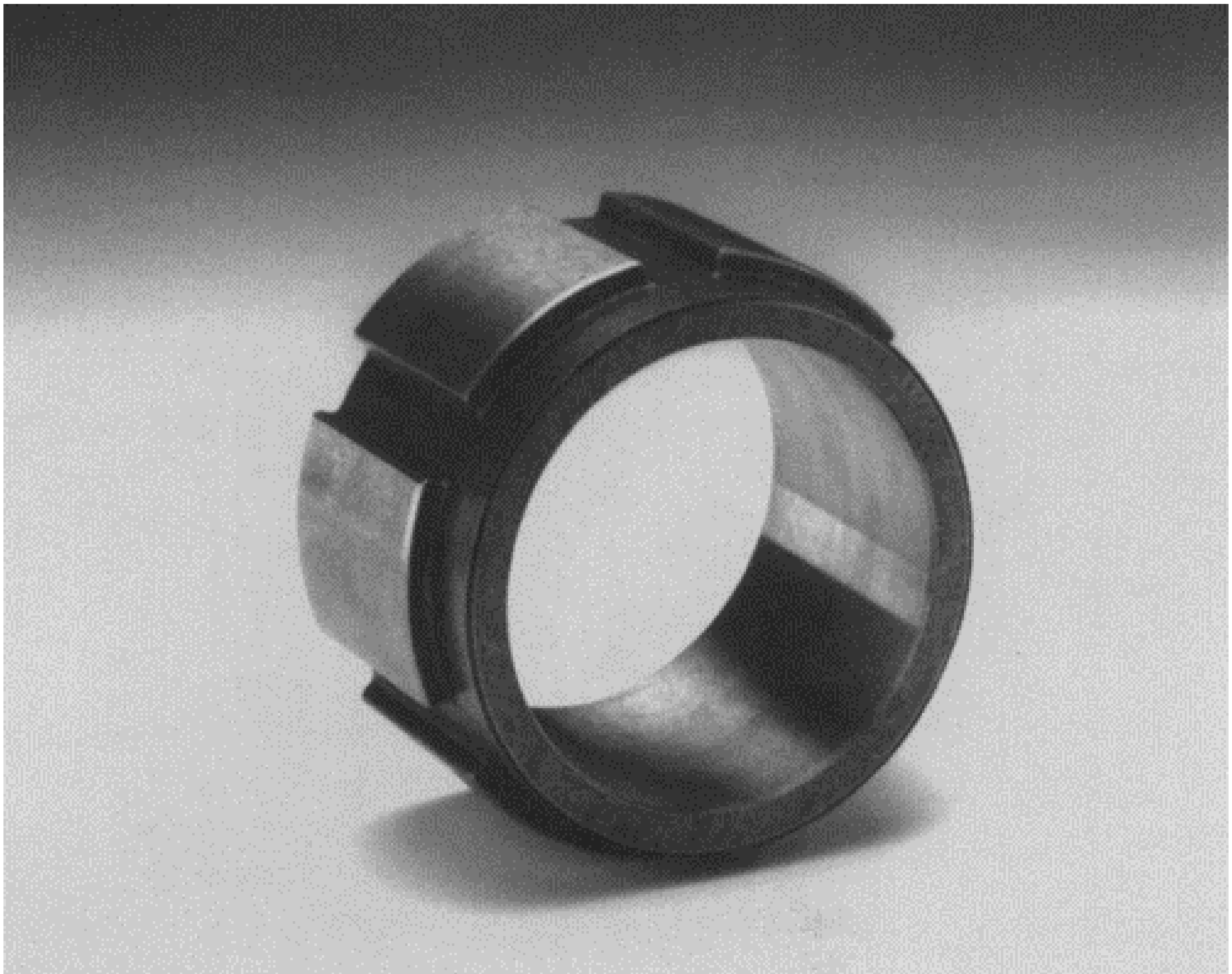
Application:	Offroad construction equipment
Part Name:	Inner transmission vibration dampening adapter
Part Fabricator:	Burgess Norton Mfg. Co.
End User:	Caterpillar Inc.
Material:	FLC-4608 sinter-hardened
Density:	6.9 g/cm^3
P/M Application Benefits:	Designed in P/M. Net shape allows processing for 50% less than wrought technology by eliminating the need for machiningoperations.
Binder Treatment Process:	ANCORBOND
Binder Treatment Benefits:	Allowed part to be ejected from the die. Improved surface finish by reducing severe scoring lines.



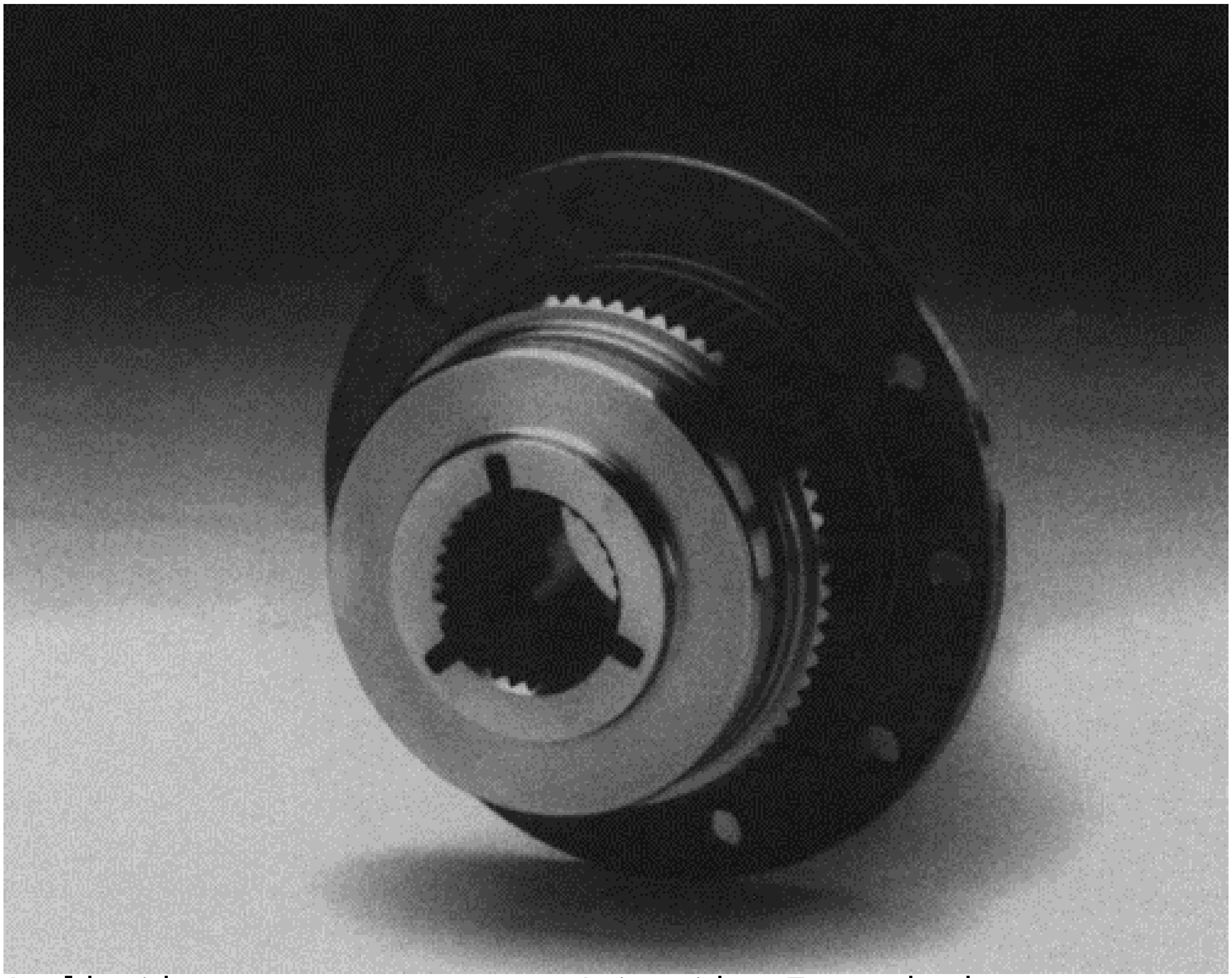
Application:	Farm Tractor
Part Name:	Transmission sleeve
Part Fabricator:	Burgess Norton Mfg. Co.
End User:	John Deere
Material:	FLC-4608 sinter-hardened
Density:	6.8 g/cm^3
P/M Application Benefits:	Replaced bar stock. Cost to produce was reduced by 50%. Improved wear resistance to the point of tripling the life of the component.
Binder Treatment Process:	ANCORBOND
Binder Treatment Benefits:	Eliminated scoring in tools. Couldn't eject the parts without this technology due to their length to diameter ratio.



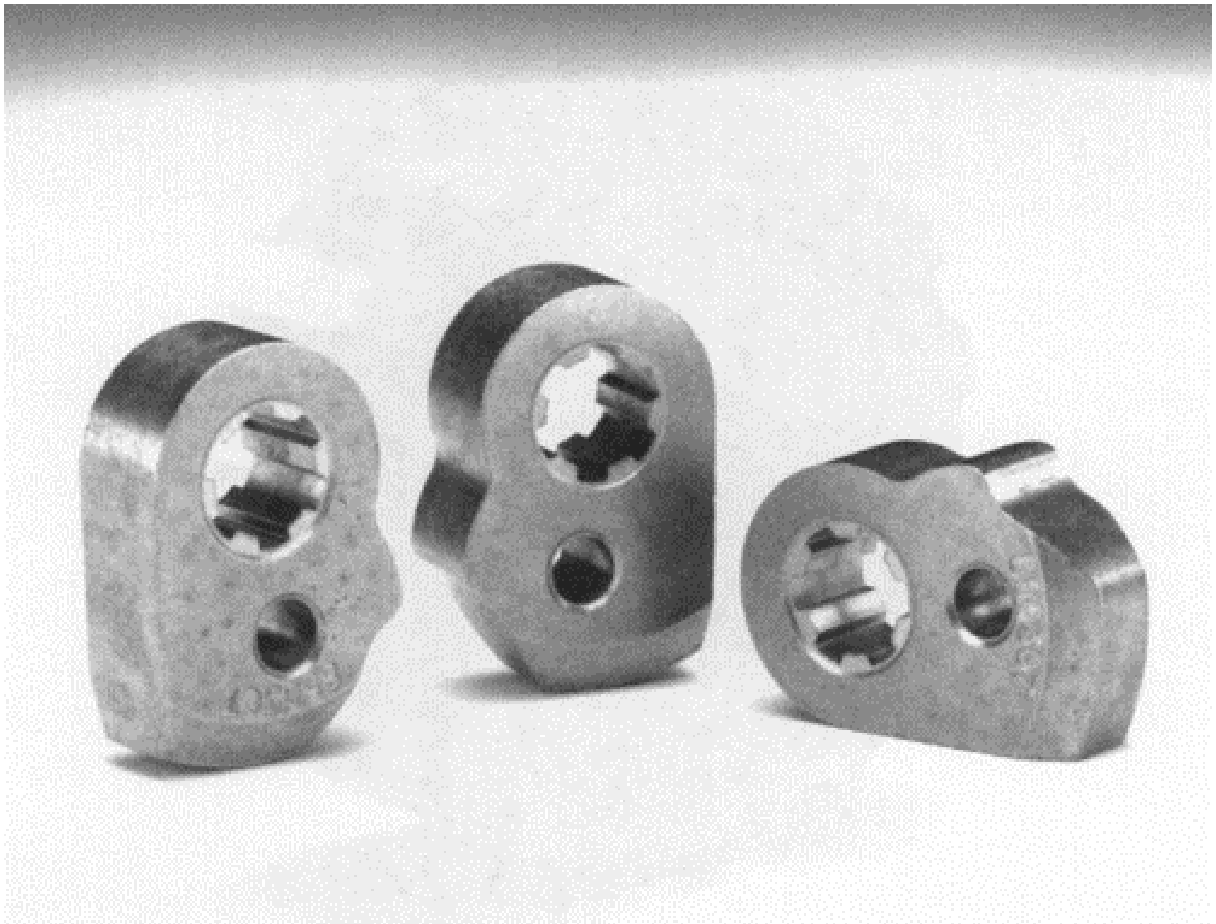
Application:	Torque on Demand 4WD Transfer Case
Part Name:	Driven Sprocket
Part Fabricator:	Borg Warner Automotive
End User:	Ford Motor Company
Material:	FN-0205
Density:	6.9 g/cm^3
P/M Application Benefits:	Conversion from a wrought component yielded a 20-25% cost savings
Binder Treatment Process:	ANCORBOND
Binder Treatment Benefits:	The ANCORBOND processed material provided significantly reduced segregation and dusting in the operator air space as shown in Figure 2. Press speeds were increased by 10-15% while improving the flow and fill consistency of the parts.



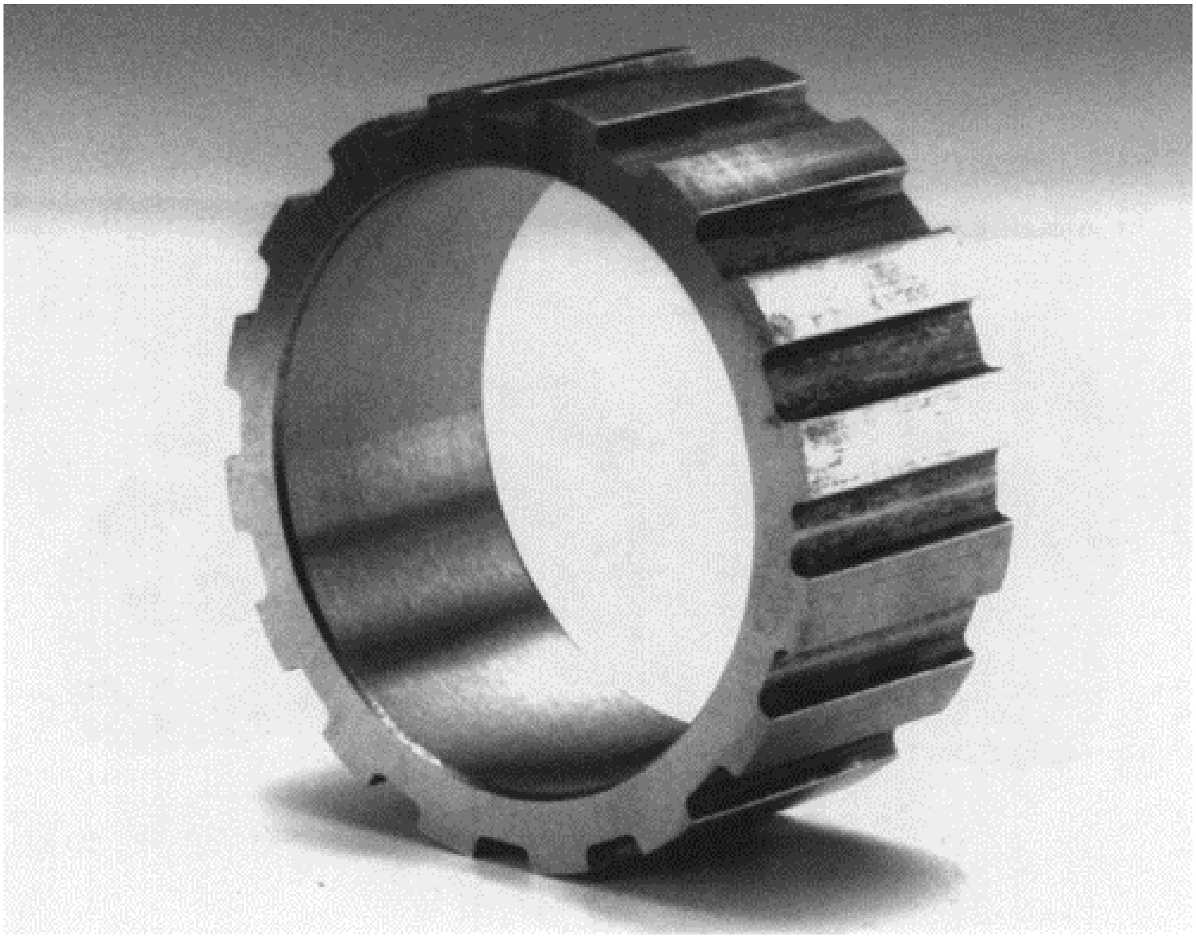
Application:	Farm Tractor
Part Name:	Transmission sleeve
Part Fabricator:	Burgess Norton Mfg. Co.
End User:	John Deere
Material:	FLC-4608 sinter-hardened
Density:	6.8 g/cm^3
P/M Application Benefits:	75% more effective than wrought steel. Significantly improved reliability
Binder Treatment Process:	ANCORBOND
Binder Treatment Benefits:	Improved finish by eliminating galling during ejection.



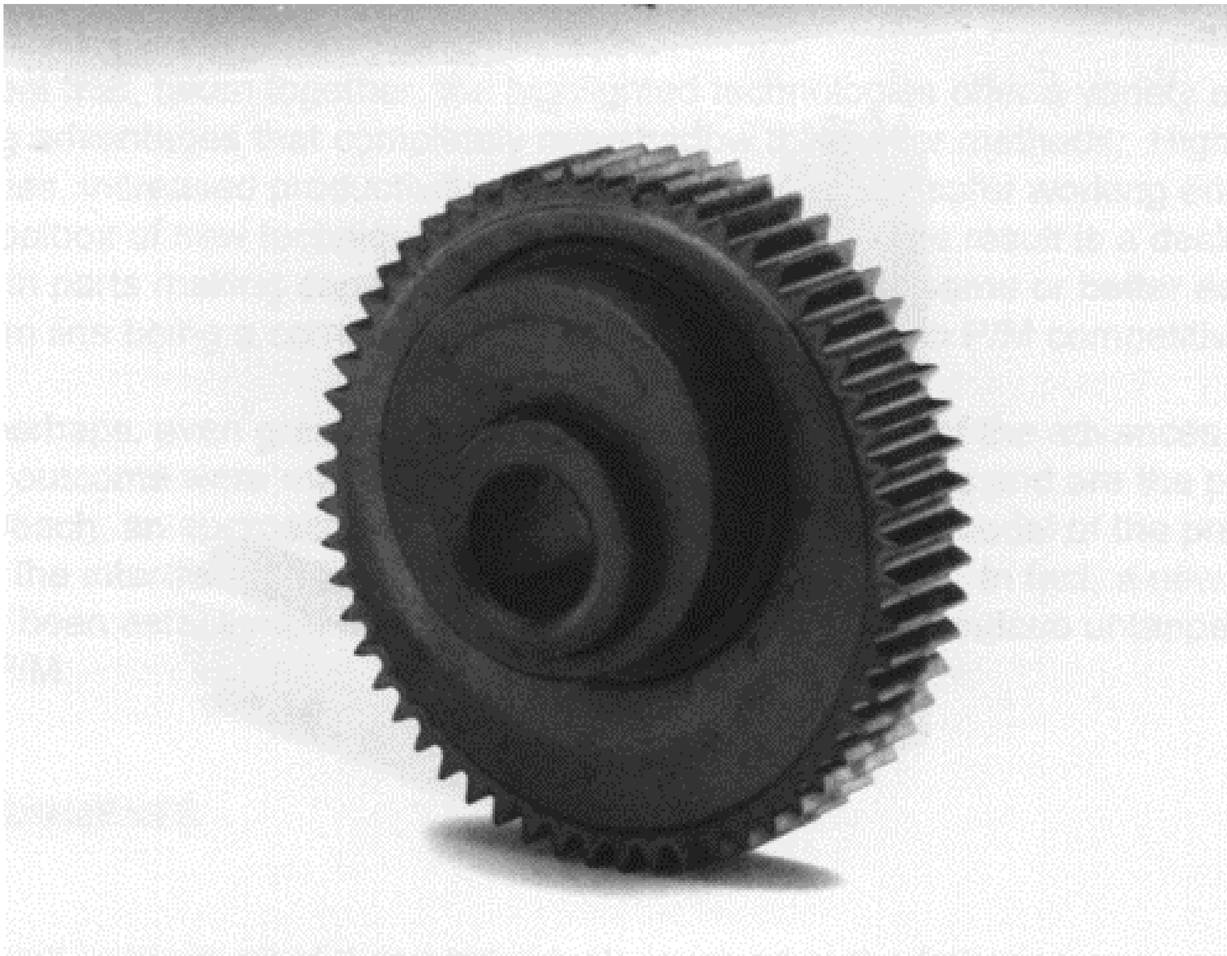
Application:	Automotive Transmission
Part Name:	Torque Converter Turbine Hub
Part Fabricator:	Chicago Powdered Metal Products Company
End User:	Ford Motor Company
Material:	Distaloy®***
Density:	7.3 g/cm^3
P/M Application Benefits:	P/M and ANCORDENSE technology provided > 30% cost savings over a machined forging. The near net form eliminated the need for an extensive number of machining operations and auxiliary components.
Binder Treatment Process:	ANCORDENSE
Binder Treatment Benefits:	The ability to achieve high levels of uniform density led to elimination of heat treatment by providing superior performance and reliability in relation to the forge and machine technology.



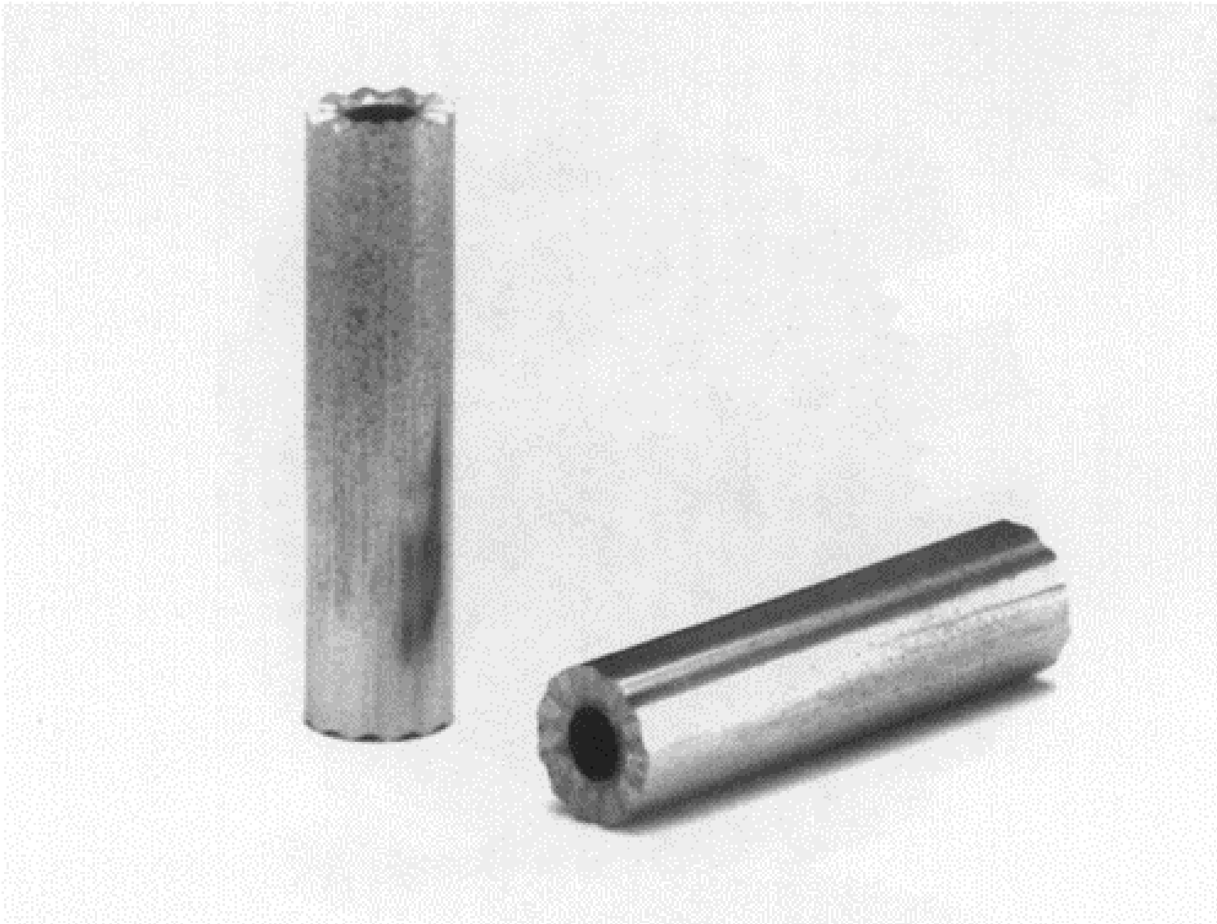
Application:	Outboard Motor Gear Box
Part Name:	Shift Cam
Part Fabricator:	St. Mary's Carbon Company
End User:	Withheld By Request
Material:	FL-4405
Density:	7.3 g/cm^3
P/M Application Benefits:	Cost effectiveness due to near net shape and complicated face geometry
Binder Treatment Process:	ANCORDENSE
Binder Treatment Benefits:	Converted from a conventional FN-0208-1 O5HT to warm compaction to achieve superior performance at no added cost. Improved densification eliminated occasional fracturing that occurred during operation.



Application:	Automatic Transmission
Part Name:	Wheel Sensor
Part Fabricator:	Sinter Metals, Inc. - Emporium
End User:	Withheld By Request
Material:	F-0008
Density:	7.2 g/cm^3
P/M Application Benefits:	Converted from DPDS P/M process
Binder Treatment Process:	ANCORDENSE
Binder Treatment Benefits:	Converted a double press double sinter process to achieve a 10% reduction in production cost while improving the uniformity of density within the component.



Application:	Heavy Duty Sabre Saw
Part Name:	Eccentric Spur Gear
Part Fabricator:	Sinter Metals, Inc. - Emporium
End User:	Withheld By Request
Material:	FLN-0405
Density:	7.35 g/cm^3
P/M Application Benefits:	Designed in P/M based on near net shape economics
Binder Treatment Process:	ANCORDENSE
Binder Treatment Benefits:	Eliminated the need for a double press double sinter operation thus providing a 15% cost savings. Density performance was particularly critical in the teeth.



Application:	Windshield Wiper
Part Name:	Spacer
Part Fabricator:	Withheld By Request
End User:	Withheld By Request
Material:	300 and 400 Series Stainless
Density:	6.25 g/cm^3
P/M Application Benefits:	Near net shape economics and utilization of a lower cost material and processing method resulted in >30% cost savings.
Binder Treatment Process:	Ancor GS-6000
Binder Treatment Benefits:	Converted from conventional lithium stearate lubricated mix. The resultant green strength improvement which was of the order of 2 to 3 times that of the lithium stearate mix led to a significant reduction in the amount of green scrap generated during handling.

CONCLUSIONS

It will be evident that, taken together, the highlighted technologies offer a variety of manufacturing advantages that completely overshadow the earlier methods. Higher densities, better properties, increased productivities, generally cleaner and safer working environments as well as a toolbox of new techniques to solve old problems. The result is a decided improvement in parts making capability that otherwise offers the same or better economy. The obvious bottom line being a correspondingly significant increase in P/M competitiveness.

Of equal or, perhaps, even greater significance is the fact that all of the advances leading to this favorable outcome were made in a space of less than ten years and are the product of a common approach, an approach that is novel both in terms of the model of the premix it assumes and the interdisciplinary team assembled to implement it. In fact, a new research paradigm has been established that is seen as possessing a tremendous untapped potential for the future of P/M.

ACKNOWLEDGMENTS

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Notes

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