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Process studies and test results for PLA and PHA grade bioplastics

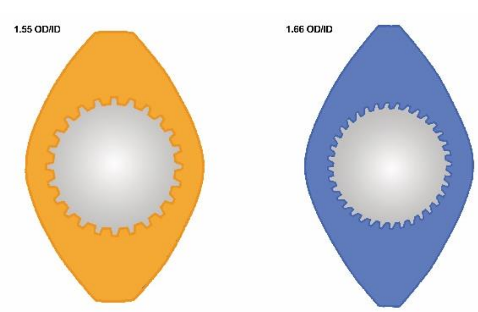
The continuous mixer of choice for bioplastics is the co-rotating, intermeshing twin screw extruder. (TSE) Bioplastic materials tend to be heat and shear sensitive as compared to traditional plastics, and generally need to be compounded with modifiers, fillers, additives and other polymers based upon the required functionality of the final product. Elevated melt temperatures and high shear stresses must be managed in the TSE process section to minimize molecular weight loss and maintain mechanical properties.

The TSE motor transmits power into the gearbox/shafts and rotating screws impart shear and energy into the materials being processed. TSEs utilize modular barrels, and segmented screws are assembled on splined shafts. This arrangement allows for a wide range and refinement of many process system configurations and applications.

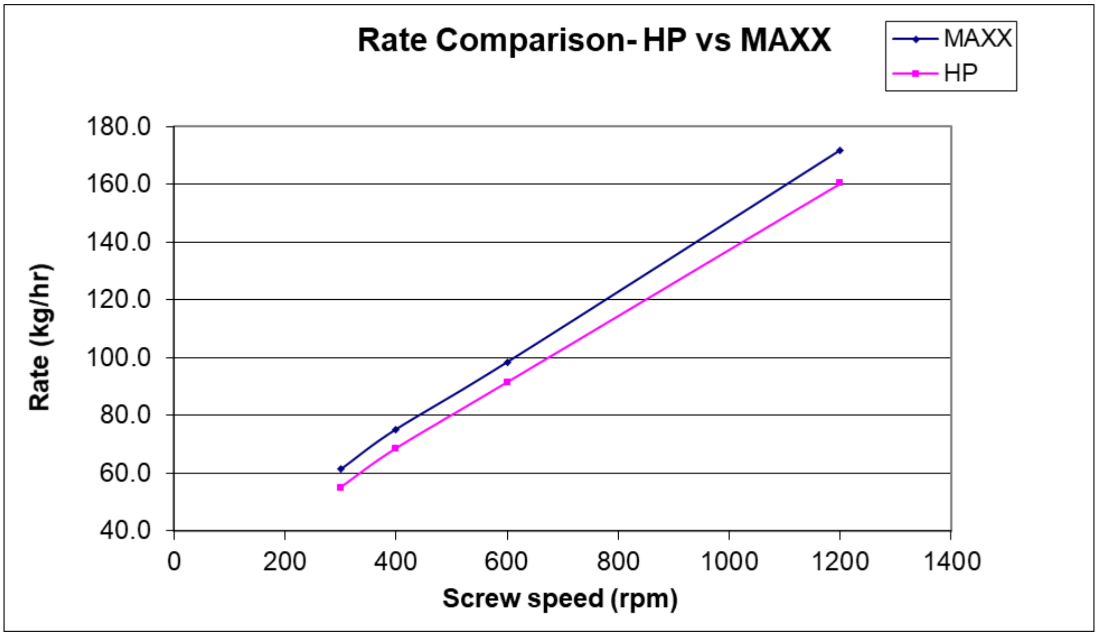
There are many grades of PLA and PHA resins. PLA is typically supplied as a pellet and requires high torque for processing. PHA is often supplied as a powder with a low bulk density. Both materials require optimized process section designs for successful processing in a TSE.

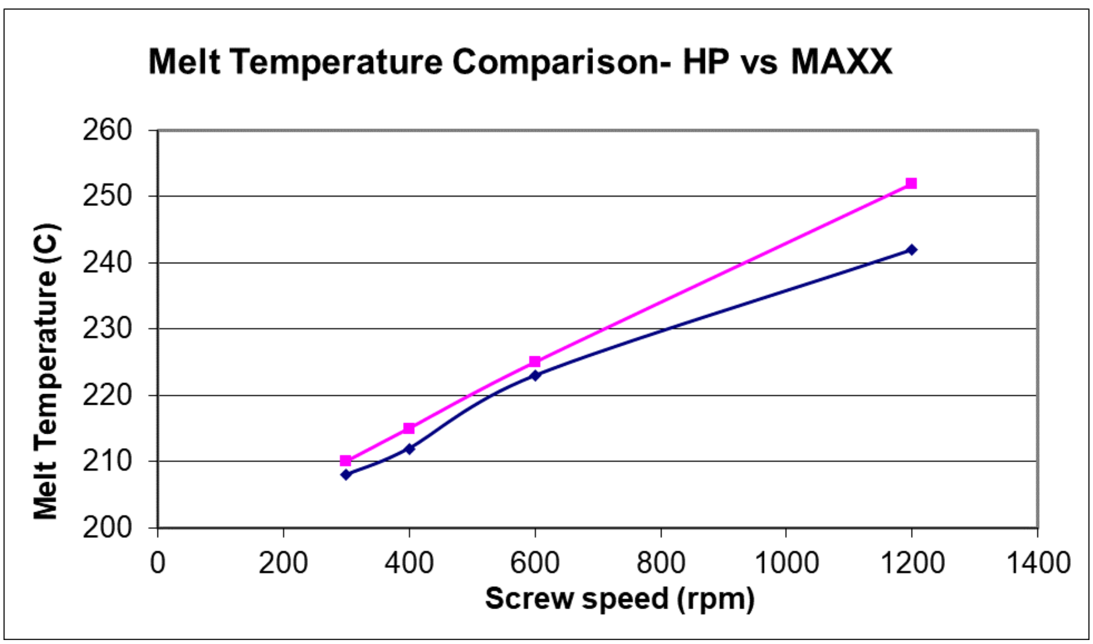
The following provide a quick summary of tests that have been performed specific to PLA and PHA resins:

Test #1 Comparing output rates and melt temperatures for TSEs with different OD/ID ratios- A PLA (NatureWorks™ 2002D) pellets were processed on a ZSE-27 HP model twin screw extruder (27 mm dia. screws, 4.5 mm flight depth and 1.5 OD/ID) and a ZSE-27 MAXX twin screw extruder (28.3 mm dia. screws, 5.7 mm flight depth and 1.66 OD/ID). The TSE screws rpms were set at 300, 400, 600 and 1200 rpms. At each rpm the rate was increased until a boundary condition was encountered, which ranged from 60 kgs/hr at 300 rpm to 160 kgs/hr at 1200 rpm. All samples were torque limited. The ZSE-27 MAXX yielded approximately 10% higher rates with lower melt temperatures as compared to the ZSE-27 HP model. At elevated rpms the resultant melt became problematic with both models. It seems that the gentler melting mechanism inherent with the MAXX design consumed less torque and allowed higher throughputs, while the lower average shear rate inherent with a deeper flighted TSE resulted in a lower specific energy and melt temperature.

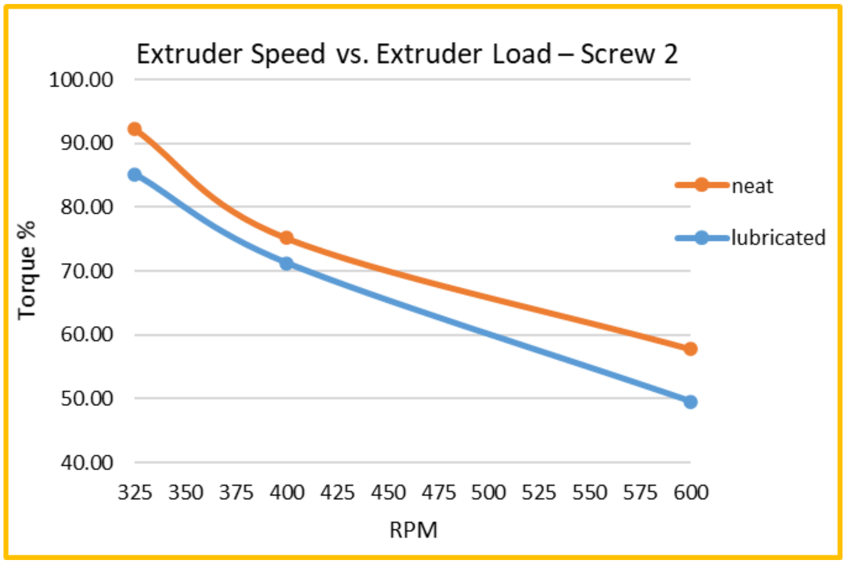


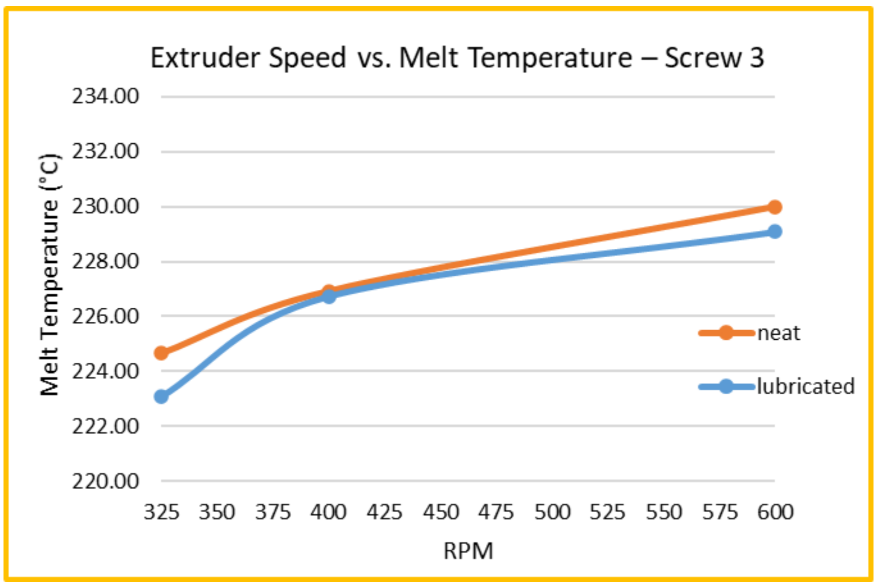
Comparison of TSE OD/ID ratios

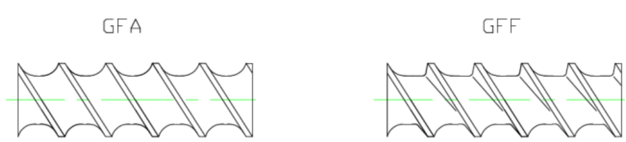




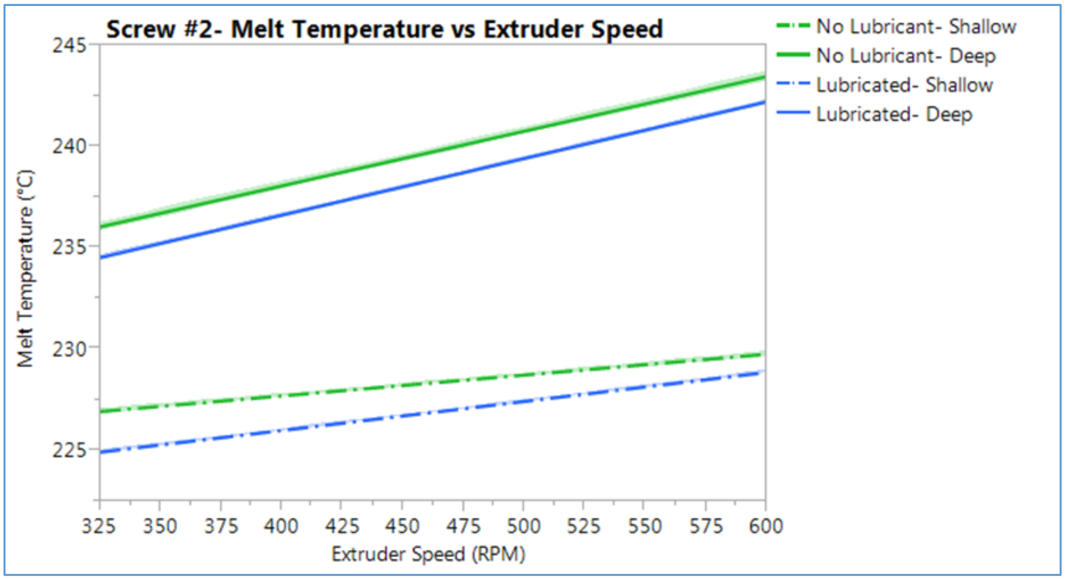
Test #2 Comparing melting zones for PLA resins- A melting experiment was performed processing PLA (NatureWorks™ grade 4032D) using three screw designs. PLA pellets with varying lubricant levels were processed on a ZSE 27 MAXX twin screw extruder (28.3 mm dia. screws, 5.7 mm flight depth, 1.66 OD/ID ratio) was set at different screw rpms with a constant feed rate of 45 kg/hr. Various screw designs were compared with different melting section designs. Delaying and modifying the melting zone resulted in lower torque and melt temperatures. Formulations were also tested with and without lubricants. As expected, when the lubricant content was increased, the torque and melt temperature both decreased. The effects of different type screw elements in the feed zone were also compared.



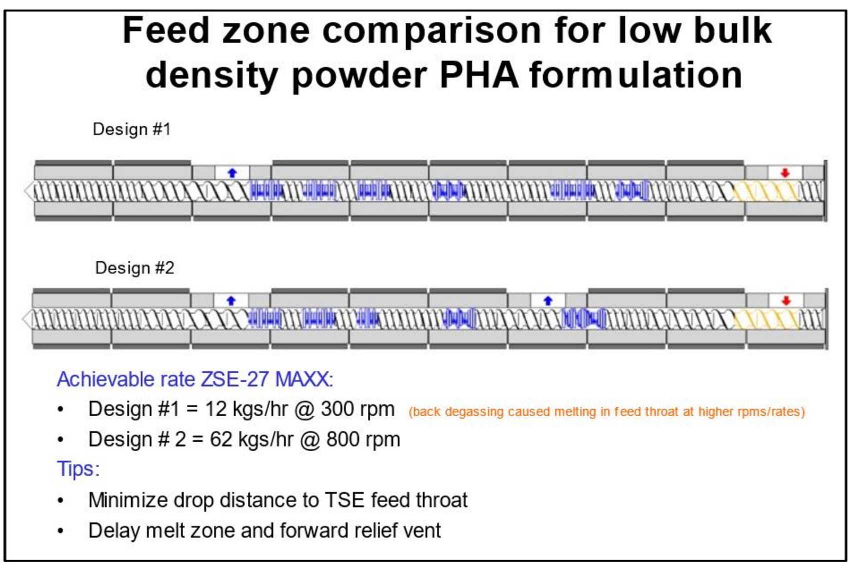




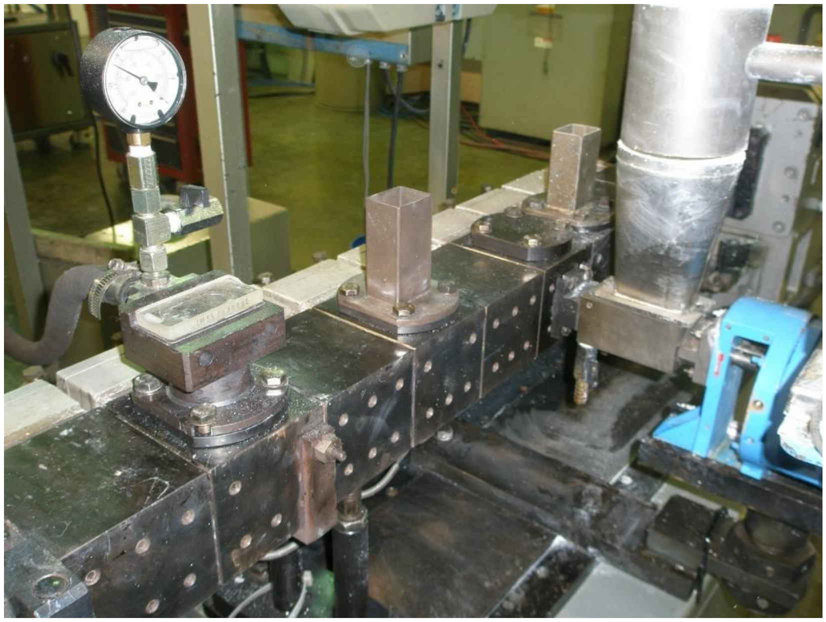
GFA = shallow and GFF = Deep



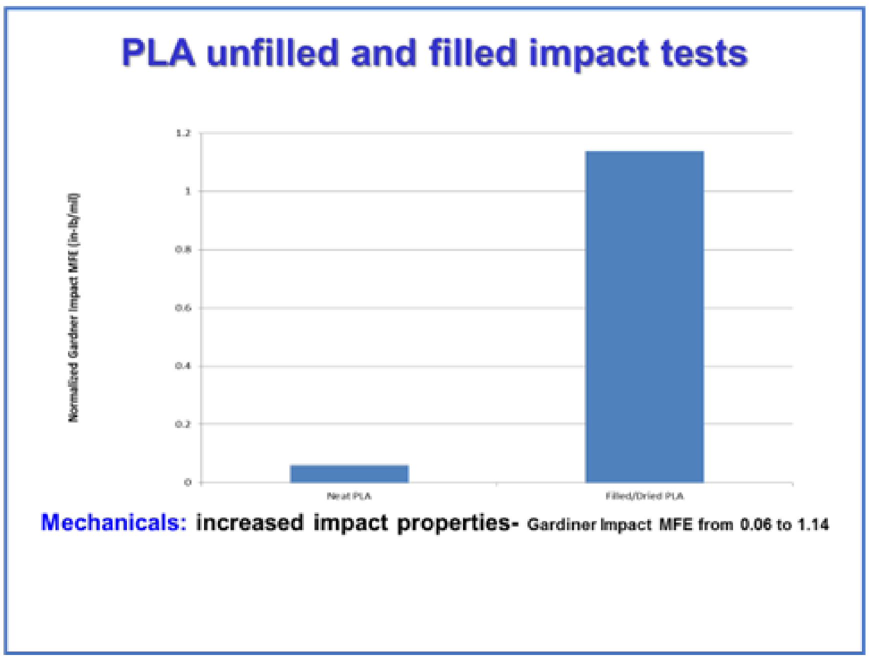
Test #3 Comparing TSE feed zones for PHA powdered resins- A series of experiments were performed processing an experimental grade PHA resin with 10% impact modifier and various additives on a ZSE 27 MAXX twin screw extruder. Initial testing was performed with a standard PE type screw/barrel design and the attainable rate was limited to 12 kgs/hr at 300 screws rpms making good product. At higher rates and screw rpms the feedstock material backed-up in the feed throat and premature melting occurred. A 2nd screw barrels design that lengthened the melting zone and added atmospheric vent early in the process section facilitated an increase in attainable rate to 62 kgs/hr at 800 screws rpm making a quality product.



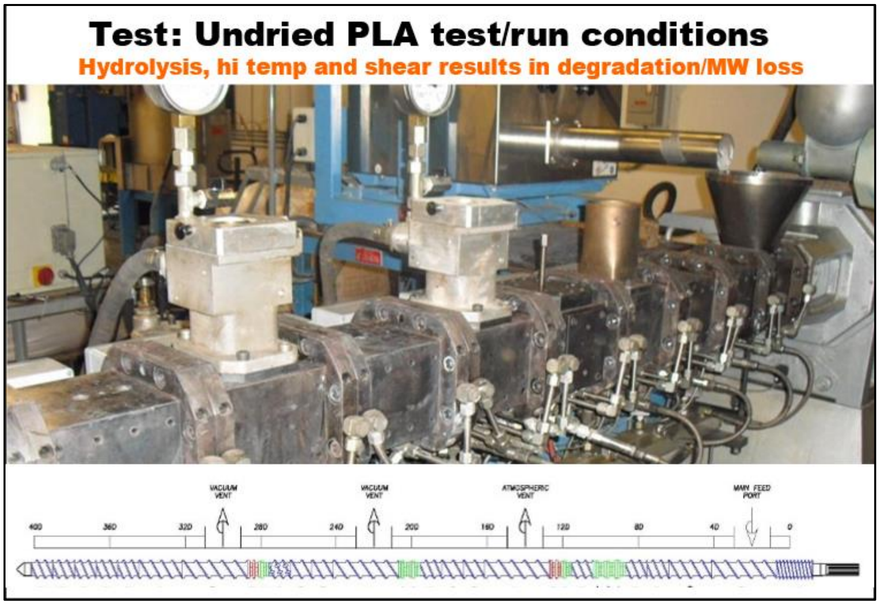
Test #4 Direct extrusion of filled PLA sheet: Testing on a ZSE-27 MAXX TSE system was performed to compound PLA (NatureWorks™ 2003D) with 25% CaC03 (Specialty Minerals EM Force™) to directly compound and extrude a sheet in one-step, bypassing pelletization and avoiding the heat and shear history inherent with 2nd step single screw extruder process. The process section and impact test results are indicated below.

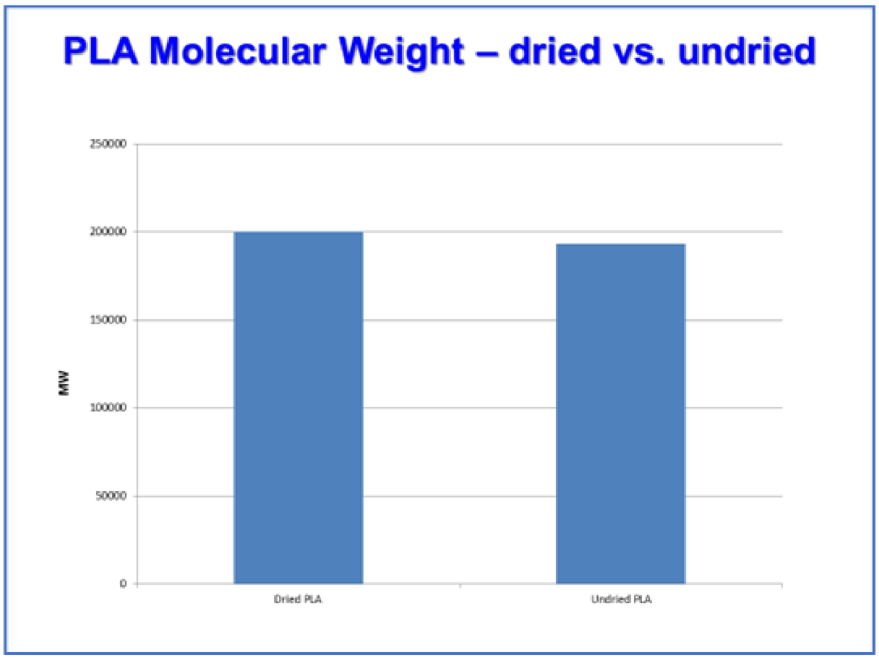


ZSE-27 MAXX process section used for test



Processing undried PLA pellets and regrind: Undried PLA pellets (50%) and edge-trim (50%) with residual moisture levels between 1500 and 3000 ppm were metered into a ZSE-50 MAXX TSE with a process section designed to optimize venting efficiencies for removal of the moisture. The process was developed and the test was performed at 200 kgs/hr and 250 rpms. The TSE process section design and results the molecular weight loss (approx. 7%) for the dried and undried samples are indicated below.





Summary: Process optimization is a key component of any manufacturing operation. Most co-rotating twin screw extruders are processing polyolefins, nylons and other "traditional" polymers. PLA, PHA other bioplastic resins are comparatively more heat and shear sensitive, and require a different hardware configuration for success. Screw and barrel designs, and operating conditions, should be modified to ensure that the process is optimized. Feeding and melting regions of the process section are a good starting point. Next is mixing, devolatilization and pumping.

The above are short descriptions of research activities conducted in the Leistritz Extrusion USA process development laboratory that have been published and presented at various industry conferences and events. Most of this work was performed in conjunction with NatureWorks™ LLC, whom we wish to thank their support in helping to develop a better understanding for processing bioplastics via twin screw extrusion.

For more details about any of these studies, or anything else relating to twin screw extrusion technologies, please contact Leistritz Extrusion for more information.