Assessing Steel Bevel Gear Design Alternatives for Sustainability Performance through Unit Manufacturing Process Modeling

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Abstract
As the growth in demand for sustainable manufacturing continues, companies must begin to make conscious design decisions with regard to the sustainability of their products. This means balancing economics of production with environmental and social performance. Thus, design and manufacturing engineers must consider economic, environmental, and social aspects simultaneously when developing products and process plans. The purpose of this research is to unify unit process-based modeling with sustainable manufacturing to create a unit manufacturing process-based methodology for product sustainability assessment. Combining these approaches allows for conducting sustainability assessment of components and assemblies at the process level by quantifying a selected set of sustainability metrics. The methodology both improves upon existing approaches in identifying the sustainability impacts of a product and assists manufacturing decision makers. A demonstration of the methodology to assess and compare the sustainability performance of three design alternatives for a bevel gear is presented, first for lightweighting and, second, for improving performance of the induction hardening process through an alloy change. For each bevel gear alternative in the lightweighting demonstration, the findings showed that the turning, vapor degreasing, and cadmium plating processes had the greatest impacts on the sustainability performance. An induction hardening unit manufacturing process model is constructed and applied to hardening the teeth of a bevel gear made from three different steel alloys, to improve the sustainability performance of the process. The model is composed of mathematical equations which are functions of process and component design parameters to quantify the economic, environmental, and social metrics of interest. The findings showed that the electrical resistivity of the steel alloy and the quenching rate had the most influence on the sustainability performance of the induction hardening process. The presented unit process-based sustainability assessment methodology and construction of unit process models can be applied to aid the investigation of tradeoffs during the design decision making process for a wide range of products.

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