Study of Process Parameters in External Thread Rolling - A Review

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Abstract: This paper summarizes the results of a numerical study conducted to analyze the effect of selected process parameters on material flow and thread profile in external thread rolling of large diameter blanks. Based on the previous work where a plane strain model was found to provide a reasonable approximation of the thread rolling process, the effect of varying thread form, friction factor, flow stress, and blank diameter on effective strain and thread height was analyzed using the finite element code DEFORM. The results of the study show that for the range of conditions considered, that blank diameter had little effect on the as-rolled thread while flow stress (K and n), friction factor, and thread form all had significant impact on effective strain at the thread root and crest and the achievable thread height. While the rate of work hardening was found to have an effect on the crest profile, the results indicate that it is not the primary factor responsible for seam formation in rolled threads.

Keywords: *MIG welding, optimization, Design of Experiments (DUE), Analysis of Variance (ANUVA), Signal to Noise (SNR) ratio*

1. INTRODUCTION

The vast majority of products used worldwide in the consumer and industrial sectors employ fasteners at some point in their design and one industry source has estimated that fasteners comprise at least one percent of the sales price of any finished product in which they are installed [1]. The auto industry, which constitutes one of the largest fastener markets, typically consumes between 2800 and 3100 fasteners in the assembly of an average family vehicle [2]. While plastics are finding increased use in low-stress applications, most fasteners used in joints requiring disassembly continue to be manufactured from alloys and metals. Externally threaded fasteners comprise the bulk of fasteners used in these applications with over 90% of being produced by thread rolling [3]. Thread rolling is a cold forming or chipless machining operation where a matched set of dies, having the reverse form of the thread, displace material to produce external threads on cylindrical or conical blanks with no material losses. While external threads can also be produced by grinding and machining, fasteners with rolled threads are preferred over cut threads. The primary reasons are lower unit cost, reduced material utilization, and superior mechanical properties. As a consequence, thread rolling has virtually eliminated thread cutting as a competitive technique for fasteners produced in quantity [4]. While thread rolling is an established manufacturing technology, process design and optimization for thread rolling remains heavily based on empiricism and shop-floor experience. Even though a substantial body of accumulated industrial experience exists regarding thread rolling, detailed information and models quantifying process behavior and linking process parameters have not been rigorously developed. Lacking the pre-requisite understanding of plasticity and flow behavior that occur during the rolling process, the capability of the fastener industry to develop advanced technological processes and optimize current levels of thread reliability will be likely hindered. Lack of a rigorous engineering basis for thread rolling has also impacted design applications which employ fasteners. Product designs that fully exploit the mechanical properties and compressive residual stresses of rolled threads have not been fully realized due to the current lack of predictive capability correlating thread properties to process parameters [5]. Thus, work to develop analytical models of process behavior and scientifically based methodologies to optimize product properties for thread rolling is clearly needed.

In order to develop a better understanding of how selected process parameters influence thread profile and metal flow during external thread rolling, a parametric study was undertaken at Marquette University with particular emphasis on larger diameter blanks. As part of the study, the relationships between process parameters, flow behavior, and thread profile were analyzed using a finite element based 2D plane strain model. Although more accurate results can be obtained from 3D modeling, the application of 3D simulation is still not widespread in practice because it is not always cost effective and requires considerable engineering and computation time [6]. Moreover, non-trivial difficulties arise in the application of 3D models to thread rolling due to the small contact areas involved and the simultaneous translation and rotation of the work piece. The results of 2D simulation, though approximate, permit expedient analysis and provide results that are nonetheless useful in understanding the mechanics of metal flow and as-rolled properties of rolled threads. In this paper, the effect of changes in blank material, blank diameter, friction, and thread geometry during external rolling of large diameter blanks is presented. The results and findings obtained from the parametric study should help to improve current understanding of how critical parameters affect the thread rolling process and form a basis for future development of guidelines for designing and optimizing rolling schedules to achieve a predetermined level of thread quality.[7]

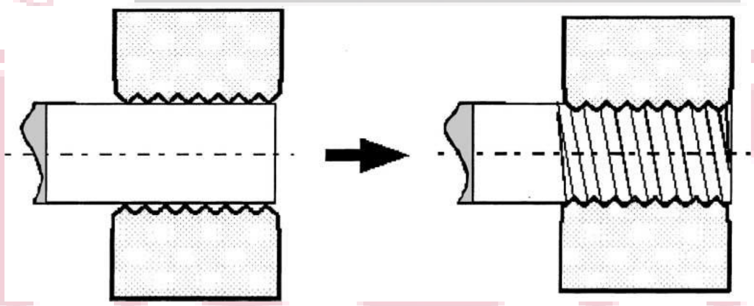

Fig. 1. Deformation and flow in external thread rolling process

2. FINITE ELEMENT ANALYSIS

Thread rolling Finite element models have been extensively used in recent years to analyze and study deformation behavior in cold forming processes such as wire/bar drawing, cold heading, and extrusion and the results have been presented in numerous papers and conferences While few 3D analyses exist, a 3D simulation of flat die rolling was recently presented, which showed preliminary results of an analysis for the flat die thread rolling process.

Parametric study conditions Because of the similarity in deformation, flat die, circular die, and planetary die configurations will have similar finite element representations in 2D. An individual thread can be considered to be ‘‘rolled’’ by progressive penetration of an indentor into the blank surface. The effective, or complete, thread form is then determined by the geometry and spacing of the individual indentors used to represent the working surface of the rolling die. Findings from a companion study analyzing smaller diameter fasteners will be presented in a future paper.

3. DISCUSSION AND RESULTS

In this section, the results and findings of the parametric study are presented. To measure the effect that changing the levels of a parameter had and to assess the impact of each parameter on a common basis, each simulation was analyzed to determine the peak effective strain at the thread root and crest as well as the percentage of full thread height achieved. While the properties of the thread flank are a critical factor in determining fastener performance, it was felt that a comparison of the effective strain at the crest and root would provide a better measure of deformation resulting from the rolling operation and a common basis for comparing different process conditions.

Analysis of material flow In external thread rolling Because threads are incrementally formed by progressive penetration of the dies into the blank surface during a fixed number of blank revolutions, external thread rolling operations (i.e. flat, planetary, and circular die) can be represented approximately as plane strain pressing of a work piece using a parallel set of wedge-shaped indentors. In view of the inhomogeneous deformation, if a substantial amount of circumferential flow occurs during rolling relative to the other directions, deformation would necessarily have to penetrate to the center of the blank to preserve continuity and prevent an out-of-round diameter from developing. The assumption of plane strain flow with negligible circumferential flow is supported by the observation that blank deformation is highly inhomogeneous and limited to the surface and adjacent sub-surface layers of the threads.

Effect of friction on thread formation Friction is another important factor in thread rolling processes in that it influences the power required for rolling and a material's rollability. Losses from friction represent a significant amount of the total power consumed during rolling and can range between 10 and 30 % of the total power consumed. Higher friction can increase resistance to flow which will also affect the capability of the blank material to form the thread profile. However, relatively little has been reported in the literature regarding the effect of friction on material flow and thread properties.

Effect of flow stress Mechanical properties along with die design and process conditions are known to have a strong influence on the thread profile developed during rolling and the tendency for a particular material to form seams. Harder materials and those having a high rate of work hardening (i.e. work hardening coefficient, n) are attributed to suppress the tendency towards seam formation in the thread crest. To investigate the effect that mechanical properties had on thread profile and deformation, two series of simulations were performed to study the effect that varying the strength and strain hardening coefficients had on rolling for a material following a power law constitutive equation.

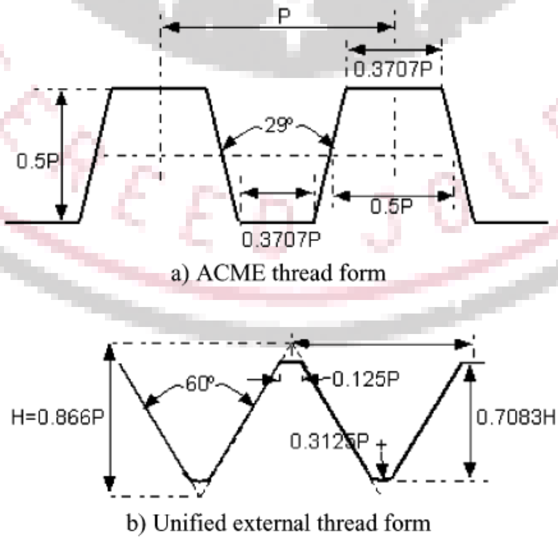

Fig. 2 Geometry of (a) ACME and (b) Unified thread forms

4. CONCLUSIONS

This paper summarizes the results of a numerical study conducted to analyze the effect of selected process parameters on material flow and thread profile in external thread rolling of large diameter blanks. Based on the previous work where a plane strain model was found to provide a reasonable approximation of the thread rolling process, the effect of varying thread form, friction factor, flow stress, and blank diameter on effective strain and thread height was analyzed using the finite element code DEFORM. The results of the study show that for the range of conditions considered, that blank diameter had little effect on the as-rolled thread while flow stress (K and n), friction factor, and thread form all had significant impact on effective strain at the thread root and crest and the achievable thread height. While the rate of work hardening was found to have an effect on the crest profile, the results indicate that it is not the primary factor responsible for seam formation in rolled threads. Thread form has an effect on the effective strain generated at the root and crest during rolling. For equivalent Unified and ACME thread forms, strain will be higher at the root for the ACME thread while strain at the thread crest will be greater for the Unified thread form. Little difference is predicted to occur along the thread flanks Friction factor has little impact on thread form or height at low values which are typical of cold forming. At higher values of friction factor, the thread height will decrease. Little effect was found on strain contours at the thread peak or crest as friction factor was varied.

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