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# A new methodology for measuring galling wear severity in high strength steels

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ABSTRACT

With the increased usage of Advanced High Strength Steels, galling wear has become a significant challenge for sheet metal stamping industries. Galling, in particular, can have a large economic impact due to the high costs and lost productivity associated with manual monitoring, refinishing/resurfacing damaged tooling and formed parts, and the need to apply expensive treatments or coatings to tool surfaces. This has led to a push for automated galling wear detection systems. However, developing such systems requires an accurate measurement of galling wear severity that can be easily implemented in industrial situations. Parameters used for measuring galling wear are often difficult to collect in large industrial style trials, and can be inaccurate as they are not targeted towards characterising the localised features associated with galling wear damage. In this study, a new galling wear characterisation and measurement methodology is introduced that accurately measures galling wear severity by targeting the localised features on sheet metal parts. This methodology involves calculating Discrete Wavelet Transform detail coefficients of 2D surface profiles. A case study on a series of deep drawn channel parts demonstrates the accuracy of the Discrete Wavelet Transform methodology when compared to visual assessment of galling wear severity. Based on comparison to visual assessment the presented Discrete Wavelet Transform galling wear measurement methodology outperforms other commonly used wear measures. The methodology provides a targeted, repeatable and non-subjective measure of galling wear severity. The specific outcome of this work provides an important tool for research into galling wear monitoring and detection systems in sheet metal forming, and the study of galling wear and its prevention in general.

## 1. Introduction

Galling wear and premature tool failure is a significant challenge in sheet metal stamping and is becoming more widespread with the increased use of Advanced- and Ultra-High Strength Steels [1]. The monitoring and assessment of galling wear on deep drawing tools and the resulting damage to formed parts is of great importance in industry, as the cost of manual quality assessment, refinishing parts, and maintenance down time is significant [2]. Measurement and characterisation of this galling wear in real deep drawing situations is a crucial component in the development and implementation of accurate real time wear monitoring systems. The techniques and parameters that have been used for quantifying and characterising galling wear are often not targeted at the localised features that contribute to and are caused by galling wear. Furthermore, these traditional techniques are not well suited for implementation in large scale industrial style stamping wear trials that are necessary for developing wear monitoring systems. This work introduces a new technique for quantifying galling wear severity using 2D profilometry measurement of the surface and analysis of this surface information using wavelet transformation. The new technique uses wavelet transformation to isolate a wavelength bandwidth that effectively characterises the localised galling wear features in 2D surface profiles. The outcome of this study is to provide an accurate quantifiable measure of galling wear severity. This is performed via measurement of the workpiece (i.e. part) surfaces and not the tool surfaces and is therefore appropriate for application in both laboratory-based experiments and industrial style wear trials. These trials are necessary for the development of automatic galling monitoring systems needed by sheet metal stamping industries to reduce the costs associated with galling wear on stamping tools and parts.

## 2. Background

### 2.1. Galling wear measurement

Galling wear in sheet metal stamping is a localised multistage

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sliding wear mechanism, where material transfer occurs at initiation sites and accumulates with progressive contact. The accumulated material ploughs the opposing surface and eventually the continual accumulation of galled material can result in fracture [3–5]. Galling wear damage is characterised by macroscopic localised roughening of the surface, and the creation of protrusions above the original surface due to plastic flow of the material and material transfer [6]. Galling is the wear mechanism often seen in sheet metal stamping, particularly deep drawing, where the tooling experiences repeated sliding contact under high loads with sheet metal blanks. These contact conditions and the disparity in surface roughness and hardness between the blank material and press tooling accelerates the development of galling wear.

Galling wear in sheet metal stamping is difficult to characterise and measure because of the multistage progression of the mechanism on both contacting surfaces and the lack of targeted measures. Wear damage features that precede galling observed in sheet metal forming progress through a number of stages including: asperity smoothing and plastic deformation, abrasive damage of various scales and finally progressing to galling damage [5,7,8]. These distinct surface features can be observed on both the tooling and formed parts [9]. Characterisation is further complicated in sheet metal stamping of irregularly shaped parts, where varying contact conditions can lead to localised wear that develops at different rates. The presence of wear damage can make formed parts unfit for purpose, both functionally and aesthetically, which highlights the requirement of automatic galling wear monitoring for sheet metal stamping.

Qualitative visual assessment is often used to determine the severity of wear on tooling and parts, and remains the most ubiquitous and effective method for characterising and identifying the severity of galling wear. The effectiveness of visual assessment has led to its use in numerous wear studies, often in addition to other quantitative measures [7,8,10–21]. Due to the difficulty of assessing tooling during forming operations visual assessment of formed parts is a primary method used in industrial applications for determining if tool maintenance is required [22]. Visual assessment is widely used for determining the presence and severity of galling wear in sheet metal stamping and is used as a standard in galling test methodologies [23,24]. The ASTM G98 galling test, for example, is widely used for the assessment and ranking of galling resistance of material couples. This standard utilises subjective visual characterisation of galling and provides a qualitative assessment of galling resistance [24]. A number of issues effecting the accuracy of ASTM G98 have been discussed [25], but the subjective nature of visual assessment and the need for clear and quantitative characterisation have been highlighted [26]. It is difficult to achieve repeatable results and collect a quantifiable output using visual assessment of galling wear severity. Given this, it is important to identify a quantifiable measure of galling wear equivalent to visual assessment.

Numerical rankings of galling wear severity have been used to provide a quantitative output for visual assessment [7,20,27]. However, in these instances the assessment has been made on magnified regions where the wear state is consistent throughout. Numerical ranking schemes are less suitable for industrial style trials as they are difficult to apply to larger contact regions with multiple localised instances of wear, and are time consuming when assessing numerous parts. Despite these issues, numerical rankings are an appropriate standard for comparing galling wear measures in small scale experimental conditions.

Mass and volume loss measurements of tooling are common methods for quantifying wear [11,14,19,28,29]. These methods are convenient for the purposes of modelling given the role of wear volume the in Archard wear equation [30], which has seen extensive usage in tool wear related studies. Mass and volume loss measurements give a direct assessment of the tooling and are simple to implement in laboratory wear test conditions. However, it is possible that the techniques can give inconsistent results as wear damage can occur without loss of mass, for example with plastic deformation [31]. Therefore, measuring mass and volume loss gives an incomplete picture of the wear process. Additionally, mass and volume measurements of wear are not suitable for progressive measurement in industrial style trials, where wear assessment is desired from part to part. It is also not possible to obtain mass measurements of large and heavy sheet metal stamping tooling that are accurate enough to identify small localised changes in wear.

3D profilometry of formed parts or tooling allows for assigning standardised texture parameter values, and provides insightful information about the state of the wear conditions. Christian and De Chiffre [16] assessed adhesive and abrasive wear using bearing curve parameters $S_{pk}$, $S_k$, and $S_{vk}$ and worked towards the characterisation of the prominent mechanism observed. Although 3D surface analysis has the potential to provide a complete quantitative characterisation of wear, a definitive selection of parameters for galling wear quantification has not been identified.

2D profilometry can also be applied to part or tooling surfaces and several standardised 2D roughness parameters are available to give information about the wear conditions. 2D profilometry has been used for the qualitative assessment of galling tracks [8] and also for collection of quantitative data using roughness parameters such as $R_a$, $R_z$, $R_y$, $R_p$, and $R_v$ [7,10,15,16]. One issue with utilising conventional parameters, particularly the average roughness $R_a$, is that they can return similar values for drastically different surface topographies [32]. 2D profilometry has also been used to measure wear track depth and estimate wear volume as a means of quantifying wear [33], however, these measures are most suitable for single wear track experiments. Fast Fourier Transform (FFT) has been applied to 2D surface profiles of galled parts in order to give a Galling Severity Index (*GSI*) [34]. This *GSI* approach assesses the 2D profiles in terms of wavelengths and takes a mean value of magnitudes within a given wavelength range, which is then normalised using a mean magnitude value for an unworn reference 2D profile. The issue with this approach is that isolating the specific wavelengths at which wear features are active is difficult as all spatial information of the profile is lost during the FFT. Additionally, taking the mean value for a range of wavelengths also has the potential for reducing or losing wear information. Despite the shortcomings of 2D roughness parameters, 2D profiles taken from parts have a distinct advantage over other methods of measuring wear. Part 2D profiles are fast to acquire, are unobtrusive in terms of press tooling, and measure the product, which is ultimately the subject of interest for industry.

Sliding abrasive wear damage produces typical cross-sectional profiles as shown by Varjoranta et. al. [35] and Yost [33]. These typical cross-sections are characterised by shoulders of raised material pile-up on either side of the depression gouge which drops below the bulk material of the surface, seen in Fig. 1. The surface features seen with galling damage exhibit similar cross-sectional features in an intensified state, larger material pile up and greater depth of gouges, shown in the

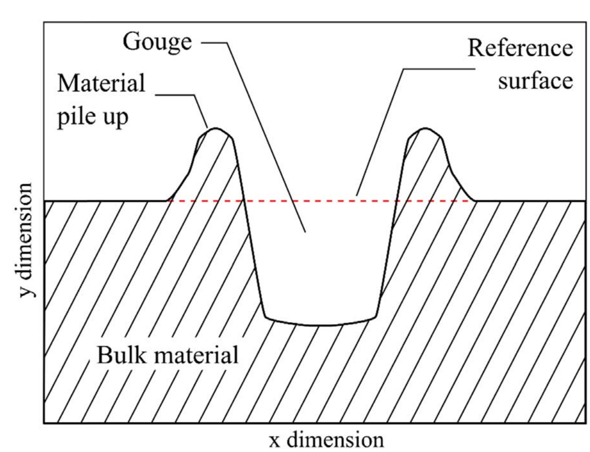


**Fig. 1.** Typical simplified cross-section of abrasive or galling gouge, characterised by the material pile-up either side of the gouge in the surface.