COMPARATIVE STUDY OF THE EFFECTS OF JOHNSON COOK PARAMETERS ON THE CONSTRAINTS APPLIED TO METALS DURING THE LAMINATION PROCESS BY NUMERICAL MODELING

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Metal rolling is one of the most important manufacturing processes in the modern world for most ordinary metals in the raw phase or in case of industrial intervention, this process can also be a solution to production situations in the case of the biological product by a significant reduction of the dimensions either under the influence of a high temperature or of the ambient temperature ,therefore and to increase the efficiency and optimize the energy required, in this paper we try to control the numerical parameters that go into this process ,metal rolling is often the first step in creating solid and standard metal shapes, Indeed, aluminum rolling offers one of the most common processes, starting from the basics of metal rolling and focusing only on the pressures applied at the back. A digital case study is provided to extract possible data. In this work, we try to study the effect of the sliding speed of the internal particles under the tangential rolling force which leads to not giving the time necessary for recrystallization in other words and according to the model of Johnson Cook will damage and by the digital simulation tool makes it possible to compare and identify it instantly.

(Received January 18, 2021; Accepted February 22, 2021)

Keywords: Johnson Cook parametrs, Rolling, Damage, Numerical modeling , FEL

1. Introduction

Rolling is a bulk metal forming process, where metal is deformed plastically by forcing it to flow between two greatly more rigid rollers, by rotating in opposite directions [1];[2]. Plastic deformation by compression reduces the initial thickness of the prismatic piece to a predefined final thickness considering elastic return. Due to the piece retaining a nearly constant volume, the amount of matter reduced in thickness results in elongation of the piece [3]; [4] (generally the difference in width is negligible compared to the variation in length), the friction force between the rollers and the piece relative to the friction coefficient is responsible for dragging the workpiece this also enhances material properties like strength, toughness and rigidity, generally performed at high temperature to consequently reduce the load necessary for deformation. The figure 1 shows a schematic diagram of a flat rolling process, where a strip of initial thickness H0 enters the roll gap and is diminished to Hf by the rigid rollers, the rollers rotate in opposite directions, given a supposed diameter noted D and an angular velocity of ω, their surface speed is thus $V = \omega.\frac{D}{2}$ .This speed of the workpiece is supposedly the same as V but given the difference in surface contact and material resistance to deformation from start to finish and the friction coefficient f this speed Varies from an initial value upon first contact V0 to a final speed Vf when the operation is completed.

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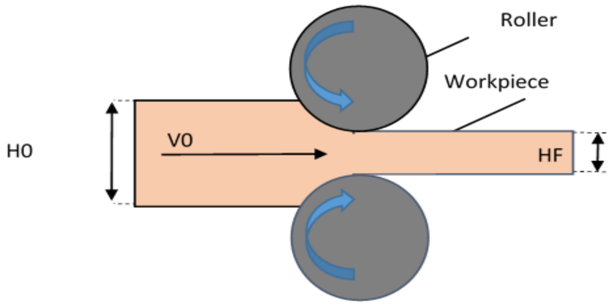

Fig. 1. Flat rolling.

As mentioned before, friction is one of the most important factors in this operation, which causes the prismatic piece to gain speed upon contact with the rollers which have faster motion, since the movement of the workpiece is strictly given by this friction, this force is in the same direction of its movement, so the speed of *the neutral plane* becomes gradually faster as material flow rate increases. The zone between the two rollers is generally known as *the lagging zone* to achieve a very accurate analysis of the flat rolling process, all assumptions such as plane strain deformation, coefficient of friction that remains constant, variable surface velocity of the rolls and constant object volume etc. are all considered. Out of all varieties of the rolling processes This process is generally so effective it produces over 40% of the total rolled products, The important of improving metal forming processes cannot be overstated and thus the goal behind this analysis is to improve the quality and efficiency of this process which could potentially help reduce costs and modify further approaches of manufacturing.

2. Formulation of the problem

2.1. Hot Rolling

This process is functionally identical to regular rolling but involves preheating the workpiece above a certain Recrystallization Temperature [5] ;[6], Which is generally between 300-400°C for aluminum, this is the most common type of rolling as it pre-relieves the metals of what is known as work hardening [7]. Raw workpieces are subjected to high temperatures (depending on the metal) before reaching rollers where additional heat is introduced in small intervals.

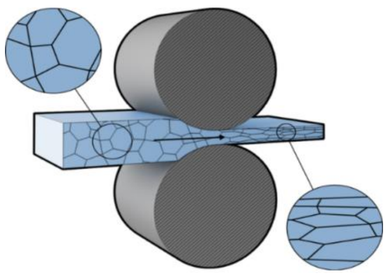

Fig. 2. Crystalline structures in Hot Rolling [6].

2.2. Cold rolling

A technique used to produce some rolled materials, these products are achieved by including clusters of rollers, generally does not reduce thickness the same way hot rolling does. It is generally applied to materials to introduce ductility into some metals like steel.

Another usage of this process is skin rolling where the thickness is barely reduced to produce a smooth surface finish to workpieces by restricting what is known as Luders bands from occurring in later processes. To restrict them, dislocations are locked at the surface reducing the possibility. and creating sufficient unpinned dislocations by density in a ferrite-matrix [8];[6] .

2.3. Material characteristics

The behavior of the material is generally assumed to be perfectly plastic elastic of Von Mises but considering our simulated work, plasticity of the workpiece is taken into consideration. The elasticity is assumed to be isotropic, using the Young E module and the Poisson coefficient. We should thus define the elasticity limit of this material (aluminum) as well as its other characteristics. One of the most often used material models is the *Johnson-Cook-Model* [9]; [10], which describes the yield stress on the material as a function of the plastic strain applied as well as temperature. To use this model for a specific object, the material dependent constants must be determined. For aluminum specifically. These constants have been determined using compression tests by means of a split-Hopkinson pressure bar [9] for usage in numerical and FEA simulations. Differences within the same material are considered negligeable and the material is assimilated as isotropic. Table 1 below is the result of a research done to deduce the necessary *Johnson Cook* parameters [11].

Table 1. Johnson cook parameters: aluminum A356.

Parameters →	Aluminum A356
A	270MPa
B	155MPa
n	0.28
C	0.018
m	1.43
Tmelt	557°C

Other parameters necessary to define the full process are Young's module of aluminum as well as its poison coefficient and its elasticity limit σ_0 (Von Mises without work hardening) [12]. Not to forget the friction between rollers and the workpiece which is a heavily influential parameter in cold rolling but still holds an importance in hot rolling. It's in turn measured with the Tresca theory as equal to $\tau = \pm \frac{k.\sigma_0}{\sqrt{3}}$ with k defined as a unidimensional friction parameter [12];[13];[14] for the transformation process speed control where the roll/metal contact occurs, the thickness reduction is suddenly not controlled by the roll force, but by metal tensions and the friction coefficient, both determining the contact stresses. This friction is in turn controlled by speed via the system hydraulic engines. Therefore, friction is maintained as moderate to keep a reasonable force and torque, but not so low as to promote sliding (more commonly referred to as skidding) [15].Since rollers are generally required to be significantly more rigid than the deformed material , they are thus generally made from tungsten-carbide which has a friction coefficient with aluminum closely equal to *0.15.* These values are defined in Table 2a -2b below [16];[17] [18].

Table 2. a characteristics of: aluminum A356.

→	Aluminum A356
Young's module E	70,000,000 GPa
Poisson's ratio	*0.334*
Density	2.7 g/cm³
Melting point	660°C
heat conductivity λ	205.0 $W.m^{-1}K^{-1}$
specific heat Cp	887
friction coefficient with tungsten-carbide μ	0.15
inelastic heat fraction with tungsten-carbide η	0.9

Table 2. b Johnson cook damage parameters for aluminum A356.

→	Aluminum A356
d1	0.1
d2	0.2
d3	-1.3
d4	0.005
d5	0
Tmelt	775°C
Ttrans	294°C
Ref strain	1

3. Roller characteristics

Since material deformation should be in its entirety directed towards the workpiece, the general mechanical parameters of the material that makes the rollers must be superior in most aspects and thus most industrial use metal rolling rollers are made from tungsten-carbide which has the following characteristics is Table 3 [19]; [20]

Table 3. Characteristics of: Tungsten-carbide.

→	Tungsten-carbide
Young's module E	550,000,000 GPa
Poisson's ratio	0.31
Hardness	9
Melting point	2747°C

Not to be considered instead the rollers will be considered a standard perfectly rigid body in order to apply the full deformation upon the workpiece.

4. Johnson COOK parameter significance

The material model used within our fem simulation for the workpiece is according to the *Johnson Cook* theory divided into three primary multiplicative influencers which are in order: f($E_{plastic}$) which describes the increase of applied stresses with an increasing plastic strains and f($\dot{E}_{Plastic}$) that describes material increase in hardness when strain rates are elevated and f(T) which describes softness at high temperatures. The yield stress can thus be calculated as [21]:

$$\sigma_{JC} = \left(A + B.E_{plastic}{}^{n}\right).\left[1 + C.\ln\left(\frac{\dot{E}_{Plastic}}{\dot{E}_0}\right)\right].\left[1 - \left(\frac{T - Tt}{Tm - Tt}\right)^{m}\right]$$

where A, B, C, n, and m are the Johnson-Cook model parameters describing the material characteristics as constants deduced from experimental measures [11] ;[22].

5. Load parameters

The load applied upon the workpiece, is given on one hand by the linear speed of the rotating cylinders

$$V = \omega.\frac{D}{2}$$

On the other hand, tensile traction stress is generally applied on the workpiece on the entry side and tensile compression stress is applied on the exit side.Thus the loading parameters are: Cylinder speed V, Entry and exit constraints σ_e and σ_s. Another parameter to consider is the vertical reduction of the workpiece which is noted as λ

$$\lambda = \frac{h_s}{h_e}$$

As well as contact length L

$$L = \sqrt{R^2 - (R + h_s - h_e)^2}$$

with h_e being the height from the neutral plane to the top before deformation and h_s being the same after deformation. To summarize this process is equivalent to an encastre of a piece with a band width L and a height equal to

2.h_e.The rotation speed of the cylinders is the only parameter including time. There is therefore no adimensional parameter associated with it.

The retained load parameters are:

the input tensile parameter: $t_e = \frac{\sigma_e}{\sigma_0}$

the output tensile parameter: $t_s = \frac{\sigma_s}{\sigma_0}$

with all previous parameters considered, a typical cold rolling process is defined by:

$$h_e = \frac{2R.(1-\lambda).\mathrm{e}^2}{\lambda^2 + \mathrm{e}^2.(\lambda-1)^2}$$

and

$$h_s = \lambda.h_e$$

and thus σ_e and σ_s can be determined it is possible to define all parameters in complete etail, but as the parameters can generally be deduced by the mathematical engine of the FEA nalysis software model they are left for the numerical analysis section.

6. Simulation model

To investigate the influence of the differing material parameters on material characteristics after processing we set up a FEA simulation model, which is suited for the calculation of utput parameters of the cold metal rolling process. The calculations are run twice for each parameter to determine the effects of Johnson COOK parameters of the material deformation and tresses applied. The simulation is set with 3 pairs of rollers each reducing the initial height of the iece by 8mm each which is an adequate value for cold rolling (generally used to reinforce the hardness of surfaces).This mesh was created with constant element densities, the pressure zones and resulting surface deformation could be simulated with the resolution. Provided, the smallest element edge length is A=2.5 mm. The work piece and the tool were modeled and thermo-mechanically coupled using elements of the type ‘C3D8R’, An 8-node linear brick, reduced integration, hourglass control. out of the element library of THE MODEL .At the beginning of each simulation the work piece was meshed by approximately 1000000 elements. The number of elements remains constant throughout the simulation. To reduce calculations, the simulation is performed on half the system, utilizing a displacement stopper on the Y axis, and then mirroring the result due to the inherent symmetry of the rolling process. With this simulation model it is possible to calculate the residual stress states as well as established parameters like process forces, magnitude of deformation pressure during the metal-deformation. The process parameters that wereren’t varied are the deformation velocity (V=70 m/min), the workpiece dimensions (80x200x500mm), the roller’s diameter (R=50mm)

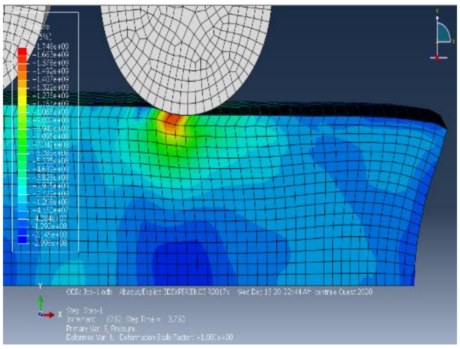

Fig. 3. Visualization of the Pressure applied In the Johnson-cook model.

The software allows us to visualize and trace several results from this visualization let us begin by tracing the residual Von-mises stresses on the material along the following path considering Johnson-cook parameters At first.

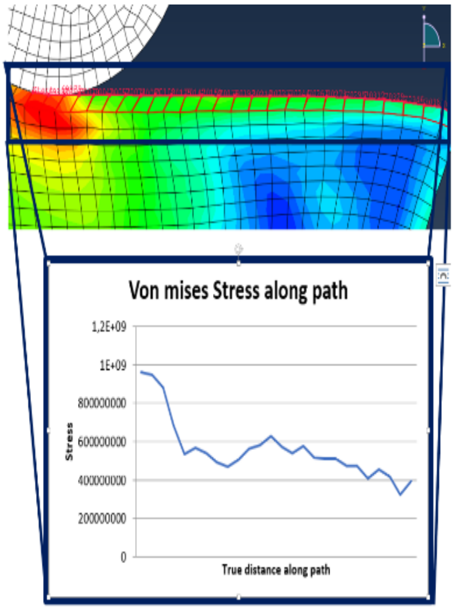

Fig. 4. Surface Von-mises stresses propagation.

To identify the residual stress states along the vertical axis, we are to consider a succession of lines that divide the workpiece along its tangential cross-section and thus we are able to plot the various outputs along them and see how they propagate through the material after the rolling process.

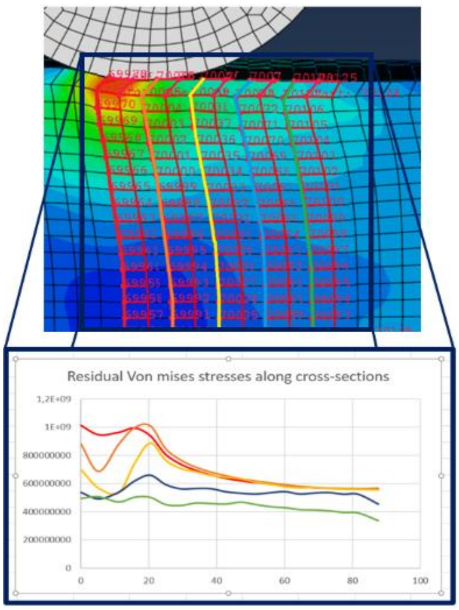

Fig. 5. Residual Von-mises stresses propagation through cross-sections.

We start our observation by comparing the values between the initial point of every cross-section, a clear dissipation of stresses as we get through the cross-sections becomes apparent, this is due to materials relaxing after the excessive pressure of the rolling process is applied, the same goes with the penetration depth where the stresses applied are less and less the deeper in the material we sink.

Other parameters important to consider are deformation and pressure applied along the top plane of the workpiece to measure the ratio between plastic and elastic deformations and thus measure the accuracy of the Johnson cook parameter system. Thus, a new path along the top-plane is selected to better visualize the exact applied forces and their subsequent deformations along the workpiece.

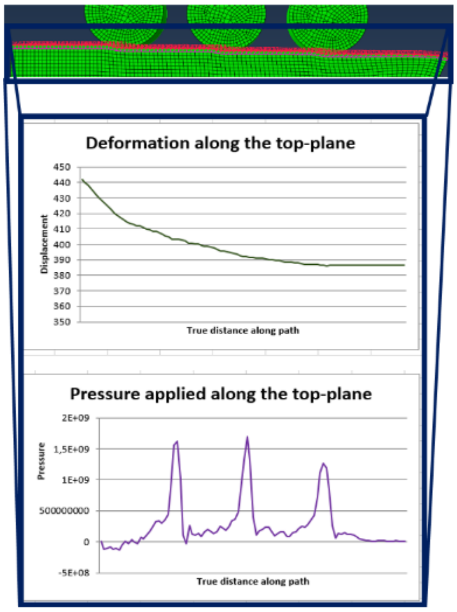

Fig. 6. Deformation and pressure along the top path.

The deformation applied to the workpiece after the third roller appears to be mostly if not entirely plastic, with some elastic return, this is due to the pressure of deformation being applied through three main peaks culminating at the contact line with the 3 rollers that eventually cause the deformation of the piece. In order to establish a point of comparison for the effectiveness of the Johnson-cook parameters we'd have to set up an identical system utilizing classical isotropic plasticity parameters as such:

Table 5. Isotropic plastic characteristics of aluminum.

Yield stress	Plastic strain
380000000	0
420000000	0.04
470000000	0.12
500000000	0.19
530000000	0.25
380000000	0
420000000	0.04

Which will replace the Johnson-cook plasticity parameters while making sure to rid our workpiece of Johnson-cook damage parameters as well.The same graphs are then traced with the new visualized model as such.

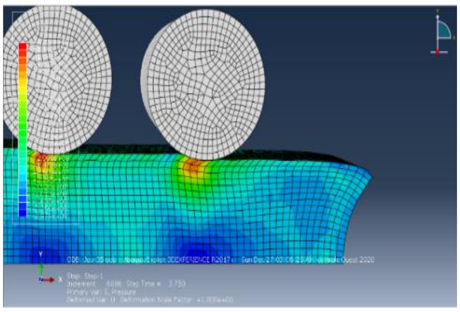

Fig. 7. Visualization of the Pressure applied in the classical isotropic plastic strain model.

The software allows us to visualize and trace several results from this visualization same way we did on the previous.

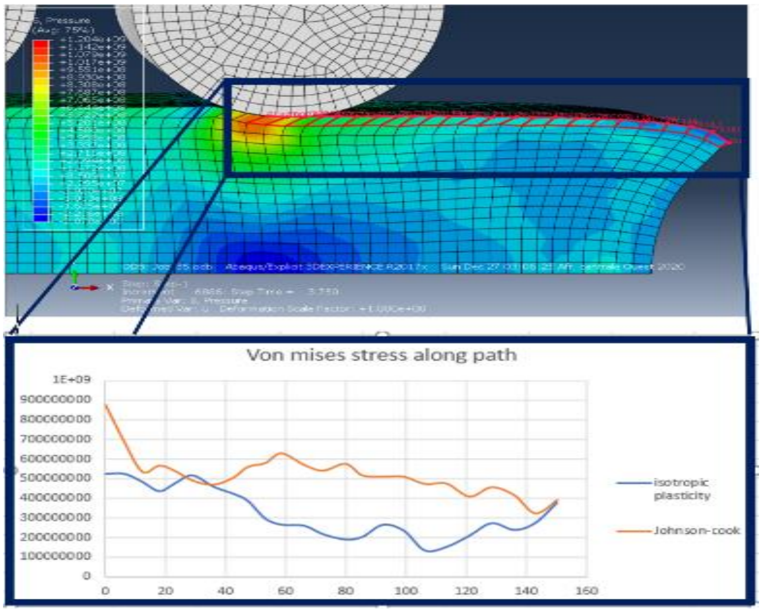

Fig. 8. Surface Von-mises stresse propagation comparison between the 2 models.

Isotropic plasticity seems to indicate a much lower initial stress value when in contact with the rollers which in turn decreases much slower as we go along the path further from the peak, this is contrarian to what is expected and thus re-enforces the accuracy of the Johnson-cook parameter outcomes. Now proceeding to compare the residual von mises stresses along various cross-sections of the workpiece. Similar to the previous work, our observation made for comparing the values between the initial point of every cross-section, which indicated a clear dissipation of stresses as we get through the cross-sections and a similar dissipation as we penetrate deeper into the material, similar results are deduced from the isotropic plasticity model, but with various differences.

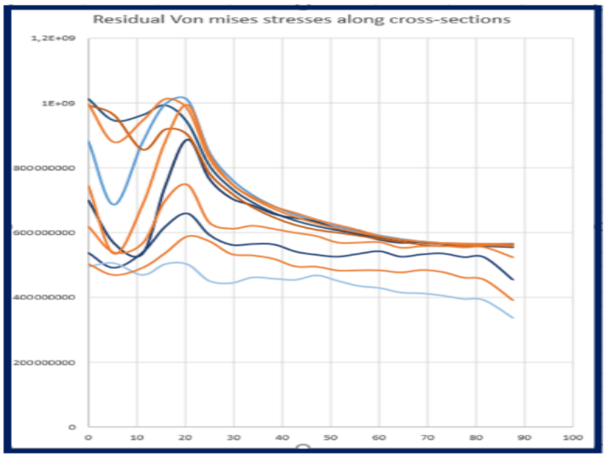

Fig. 9. Residual von-misses stresses propagation through cross-sections comparison between the tow models.

Similarly to the previous model, every cross-section that gets further from the roller indicates a dissipation of stresses and thus a reduction in the maximum value of Von-mises stresses but an important difference to note is the much quicker reduction in peak values between the Johnson cook model (in blue) and the isotropic plasticity model (in orange) this in turn indicates a quicker initial absorption of stresses yet a much weaker absorption of penetrating stresses in the depth of the workpiece. And thus, a greater risk of residual stresses damaging the material in long-term usage, proving weak to long term fatigue due to stress.

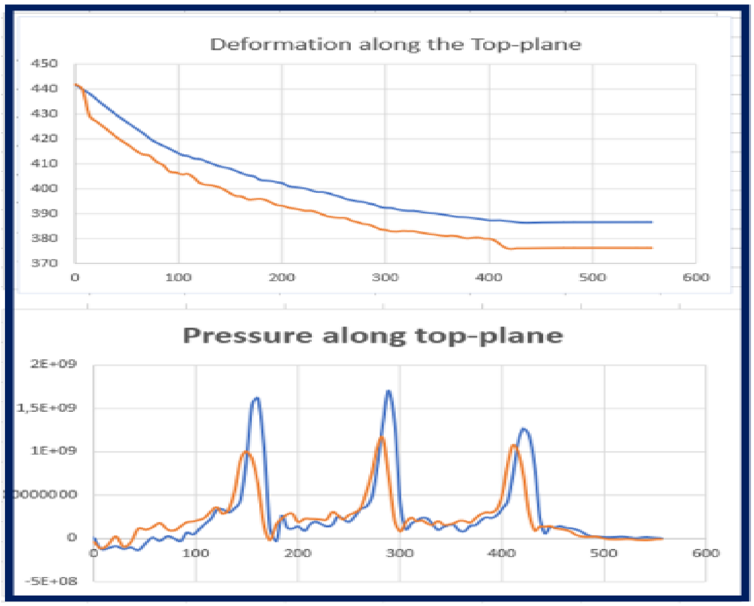

Fig. 10. Comparison between Deformation and pressure along the top path of the 2 models.

For the deformation graph we notice a lot of fissures and sudden changes of magnitude along the path instead of the desired smooth continuous reduction of the cross-section desired and identical to the Johnson-cook model, this is in part due to the differentiation in pressures applied along the top plane, where a similar shape of the graph persists with peaks along the lines where the workpiece comes in contact with the rollers, but we notice this time much lower peaks which might indicate a lower resistance of the material to plastic deformation in turn requiring much lower pressure values to deform.

7. Conclusions

The results showed that the simulation of influences on stresses and stress-dissipation depends heavily on the Johnson-Cook material parameters applied. In this connection the deformation and the pressures applied that cause this deformation have the smallest noticeable effect, only varying slightly in amplitude and peak values, while the deformation velocity and Von-misses stresses along the top-plane and cross-sections showed to be of higher importance.

The used material parameters showed very similar trends with a few exceptions, such as plastic return after deformation and heat dissipation. To iterate on this research and its results we have to compare these theoretical results to experimental measurements done under precise setups to find out which material model is most suitable in combination with the used FEA simulation model.

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