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Study of Strains Distribution in Spinning Process Using FE Simulation and Experimental Work

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Abstract

The spinning process is an advanced plastic working technology and is frequently used for manufacturing axisymmetric shapes. Spinning forming is continuous and partial deformation, so it is very difficult to control the shape, dimensions and precision of the finished parts. Because of high stress wave speed propagation, the FE analysis of spinning process is difficult. The software used is ABAQUS 6.4 which its advantage is using explicit dynamics FE formulation method. The results from the FE model are compared with experimental results obtained from NC spinning machine. The used material is commercially pure aluminium (1000 series).

Keywords: Spinning Process, Strain, FE Simulation, Experimental work

1 Introduction

This paper analyses a simple experimental shape produced by spinning. In order to understand the difficulties that metal spinning presents for finite element analysis, we must consider the nature of metal spinning itself. It is an incremental forming process that is achieved by relatively small forces [1]. The theoretical strains are considered under two idealised models. The first process, in which the thickness of workpiece is almost unchanged, is called conventional spinning and the second process of pure shear forming where the hoop strain is zero. In conventional spinning, it is assumed that the sheet thickness is constant and the hoop strain ε_h is compressive, the radial strain ε_r is tensile (i.e. the strain lying in a plane tangent to the sheet in a direction away from the axis of rotation) and the thickness strain ε_z is zero. In shear forming the radial position of any element is unchanged and a single pass is usually all that is required to produce the desired shape. Earlier authors have proposed various analysis of the spinning process. The both model presented before, are ideal models and from the view point of practicality are impossible. In this paper three important activities has been done: Using the explicit method in FE analysis of the process, optimization and a new method presentation in strain measurement by grid marking method and the simulation of actual spinning process in which none of the values of

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three main strains are zero. Therefore it is essential to study the distribution of strains in the spinning operation.

2 Model Establishment in spinning process

2.1 Basic assumptions

- The circular blank is spun to the portion of a sphere using multi pass conventional spinning.
- Both the analysis and results was gotten after the last pass and based on the distribution of strain on the final shape.
- Due to the asymmetric nature of the process and loading, the simulation is considered as Full-3D.

2.2 Specifications of process mechanical components

Figure 1 shows the specified model that was selected for the simulation purpose. The actual spinning equipments can be seen in Figure 2.

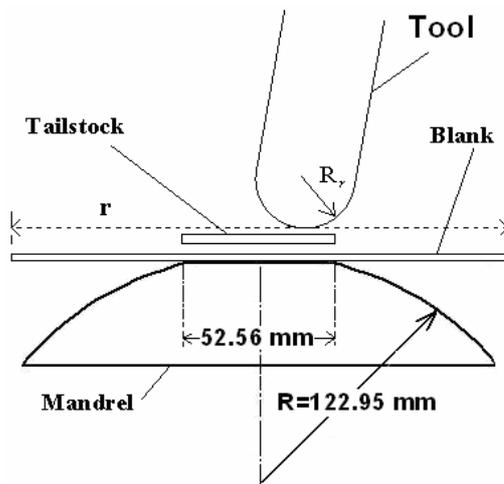


Figure 1: A Schematic model of Spinning process.

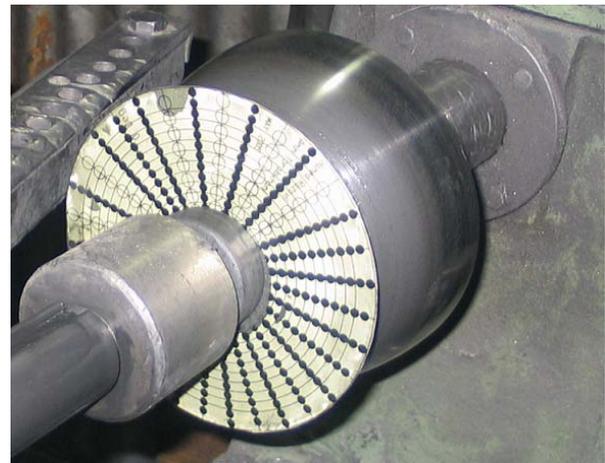


Figure 2: Spinning in progress on NC lathe.

A simple shape was chosen as a mandrel from mild steel material. The shape consisted of spherical surface of radius 122.95mm, and the top section of spherical shape is considered flat to let the tailstock clamp center of the blank against the mandrel. The material for the blank is commercial pure aluminum (Al 99.0, 1000 series) and its mechanical properties are as follows: Young's modulus $E=71000\text{Mpa}$, Poisson's ratio $\nu=0.3$, initial yield stress $\sigma_{y0}=90\text{Mpa}$, mass density= 2700Kg/m^3 . A variety of blanks with different diameter and thickness was used. The larger the diameter of the blank and the smaller the relative thickness causes the greater the probability of buckling failure mode during the process. However in the spinning of the blanks with smaller diameter, no such difficulty appears with the exception of possible wrinkling in the outer peripheral region of the blank. A size of $r=102\text{mm}$ diameter and $t=1\text{mm}$ thickness was chosen for further investigations. The tool which is used for deformation in spinning process is a wooden tool with the spherical head of radius $R_t=15\text{mm}$. Tools of mild steel and wood were used and the latter gave better results in that there was less tendency to groove the work piece and therefore



easier to achieve a uniform results. Moreover, wooden tool does not damage the printed grid used for strain measurement on the blank surface.

2.3 The selection of process parameters

The selected model is one of the most common established applications of the spinning which is in wide use in industry. The lathe was powered by a 250 W motor, which drove the spindle at 750 rev min^{-1} . The lathe itself was a conventional lathe for turning and spinning purposes. The process control in manual spinning is viable since the operator can sense whether the blank is to buckle, thereby adds a further tool movement and tool passes to handle the occasion. Some authors such as Quigley and Monaghan suggested that using the force controlled techniques would be more easily than existing position controlled equipments in most conventional NC lathes to determinate tool movements and number of tool passes [1]. The multi pass process has a great effect on improving the surface roughness and forming limit [2]. The effect of tool path on the quality of the formed parts and success of or not of spinning process was studied by Wang in [3]. The difference between conventional spinning and shear forming is that in practice, conventional spinning is a multi pass operation, but in shear forming, a single pass is usually all that is required to produce the desired shape. However a multi pass operation with tool-traces according to Figure 3 was used.

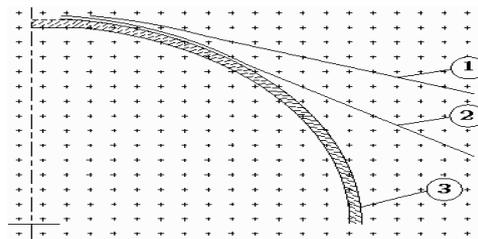


Figure 3: The used tool-traces in multi pass spinning.

3 FE analysis

It has been tried to be maximum similarity between FE modeling of spinning process and setting of experimental work. The software used in this paper is **ABAQUS 6.4**. From the viewpoint of model geometry, the spinning process is essentially an axisymmetric process while the loading method is completely asymmetric. In any given time, only a small portion of the work piece is in contact with the tool, and a very small tool movement can profoundly affect the process. Accordingly, the process modeling should be unavoidably done as Full-3D model. Previous authors suggested some ideas for FE simulation [1, 4, 5]. The transient stresses and strains that occur during spinning process can be measured only in FE simulation, and it is very important. The subjects presented below, are coming in the order which ABAQUS simulation stages propagates. The mandrel and tools are defined as rigid analytical surfaces during the simulation; they do not require to be meshed. The blank is only deformable body in the model. ABAQUS has two kinds of analysis: ABAQUS/Standard (Implicit), and ABAQUS/Explicit [6]. ABAQUS/Standard is a general-purpose analysis product that can solve a wide range of linear and nonlinear problems involving the static, dynamic, thermal, and electrical response of components. It is more efficient for solving smooth nonlinear problems. ABAQUS/Explicit is a special-purpose analysis product that uses an explicit dynamic finite element formulation. It is suitable for short, transient dynamic events, such as



impact and blast problems, and is also very efficient for highly nonlinear problems involving changing contact conditions, such as forming simulations. The explicit dynamics procedure is ideally suited for analyzing high speed dynamic events. The direct-integration dynamic procedure provided in ABAQUS/Standard uses the implicit Hilber-Hughes-Taylor operator for integration of the equations of motion, while ABAQUS/Explicit uses the central-difference operator. The time increment in an explicit dynamic analysis can be very short if the mesh contains small elements or if the stress wave speed in the material is very high. However problems involving high stress wave propagation can be far more efficient computationally in ABAQUS/Explicit than in ABAQUS/Standard. Also ABAQUS/Explicit contains a parameter as a mass scaling factor that it causes the mass matrix to be partly modified where consequently the stress wave speed decreases and the minimum time increment increases. The mass scaling factor should be considered a value that the total mass of the model doesn't change so much; otherwise the results won't be reliable. Valuing the mass scaling factor is still under investigation. Explicit method is restricted to first-order, pure displacement method or modified second-order elements. In some cases the choice between the explicit and implicit is obvious, but in many problems of practical interest the choice depends on detail of the specific case. However because of high stress wave propagation speed in spinning process, the best method is using of ABAQUS/Explicit. The friction rolling coefficient between the tool and the blank is set to 0.02 as it falls to be a low friction. The Contact surfaces between blank and mandrel are defined as frictionless surfaces. The blank is partitioned into two separate cells using of a central cylindrical cell of radius 26.5mm, then the central cell is constrained to the mandrel and consequently the tailstock can be omitted in the simulation. In fact because tools are not rigid, the distance of the tool from the mandrel is set increased in the model by 0.05mm from which would maintain a distance of the tool from the mandrel. It is used the angular velocity of $20(\text{rev/sec}) \times 2\pi(\text{radian/rev})$ to the central axis of the mandrel which is constant during operation. The mesh assigned to the central partition is hexahedral with sweep technique, and the outer partition of the blank is meshed by hexahedral element shape and structured technique. The solution time depends on the number of elements meaningfully. The mesh must be fine enough to allow in each time, more than one element make contact with the tool, therefore the continuity of contact and results precision increase. The effect of number of increments per element was studied in [1]; it suggested that three or four increments per element entering the contact region provide a reasonable compromise. However the length of time increment in ABAQUS/Explicit is determined automatically.

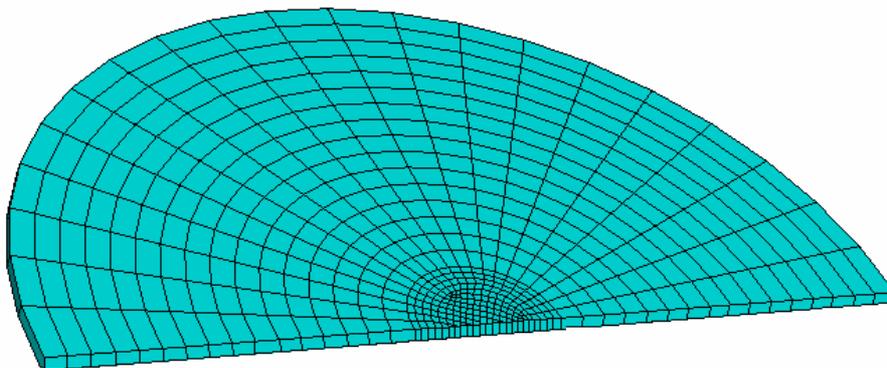


Figure 4: Mesh detail.



Figure 4 shows the detail of a typical mesh. One element was used through the thickness of the sheet. The circumference is divided into 42 segments and the radius of blank is divided into 18 elements along 75.5 mm from the edge of central partition to the outer edge of the blank. The elements of the portion of blank from radius 26.5mm to 35mm is divided by two in radial direction for more precision of results. The shapes of elements are more like those of a flat tile than a brick, although ABAQUS doesn't recommend aspect ratios greater than 3, but because of some solution time limitations, this is ignored. The computers used for these simulations are Intel 3.0 GHz (800 MHz Bus, 1024 cash) single processor and dual processors PCs with 512 MB RAM. The simulation of spinning process is very time consuming and the solution time for this reason is between 90-120 hr; of course this time varies strongly by little changing in elements number. The effects of parallelization, domain decomposition and multiple processors on the solution time were studied in [1, 4]. Also using restart operation and its advantages and applications were studied in [1]. ABAQUS/Explicit has a parameter as **Recover** where it used for some power failures. After recovering operation, all conditions could be adjusted to before power failure. Figure 5 shows various stages of the FE simulated spinning process. Figure 6 shows strain curve against radial distance from the spinning axis R_n , which is obtained from FE simulations.

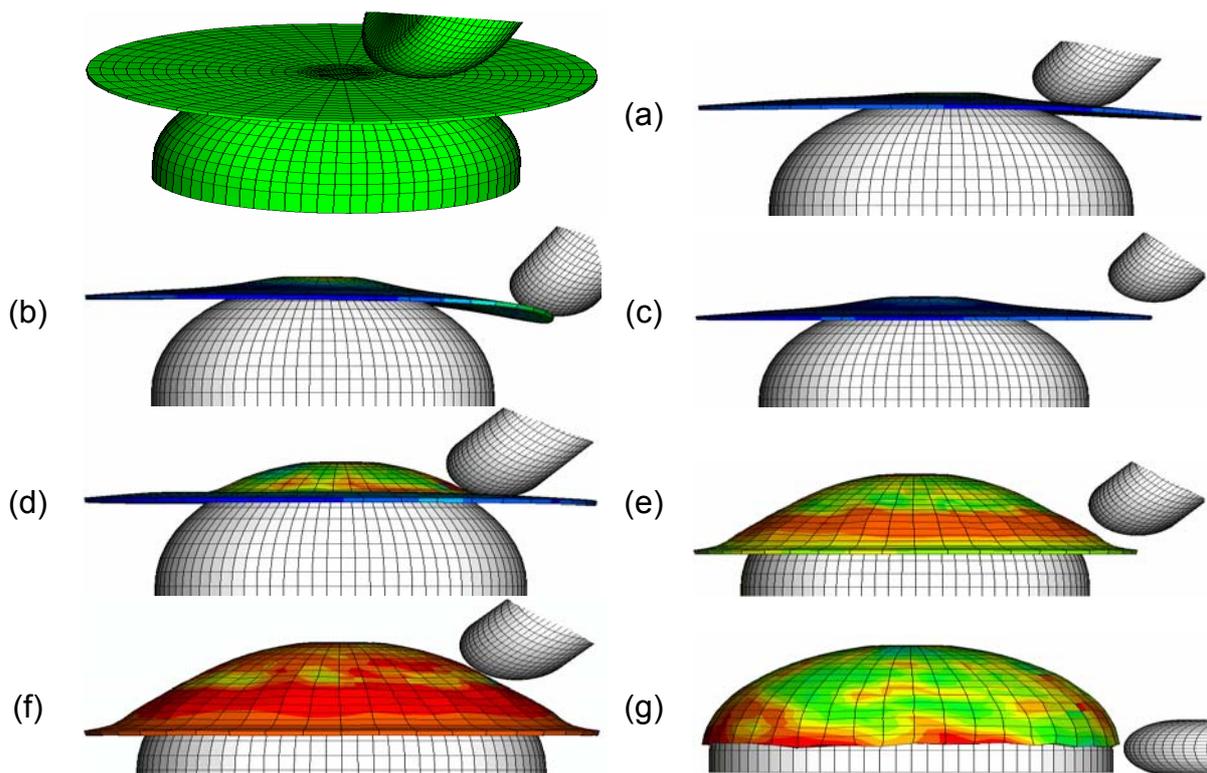


Figure 5: FE simulation of spinning in progress.

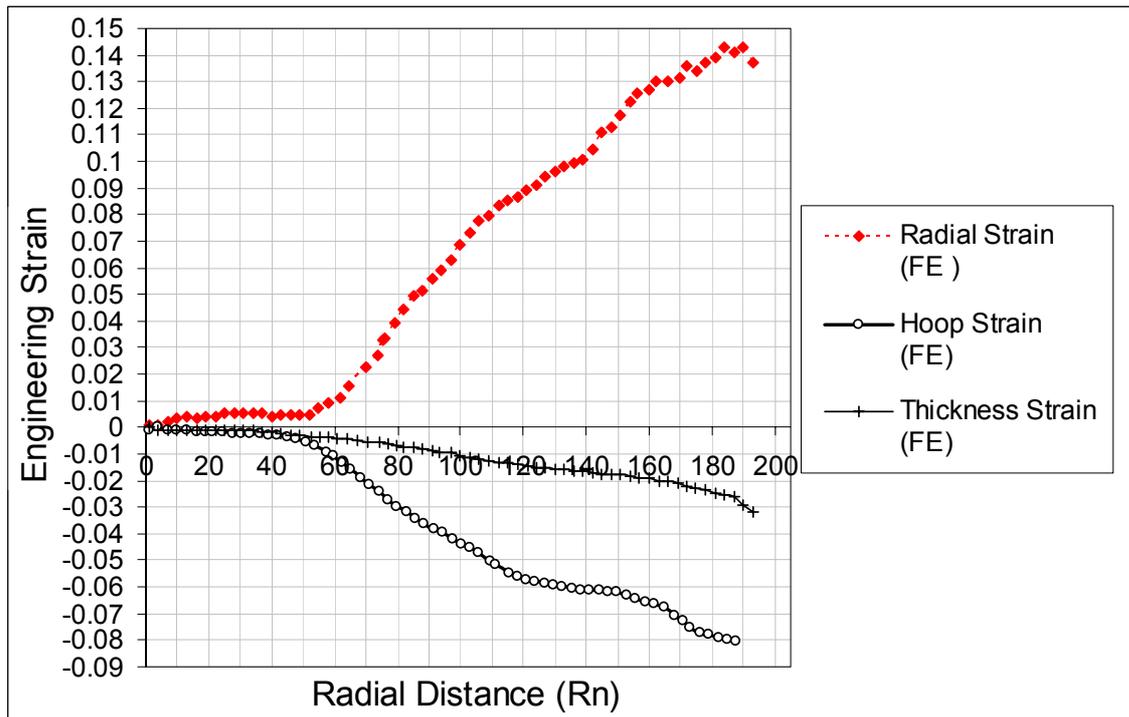


Figure 6: The diagram of strains arising from FE simulation of spinning process.

4 Experimental work

The blanks, mandrel and tools with characteristics presented before are provided for experimental work. Also, a NC spinning machine which drove the spindle at 750 rev min^{-1} was used. The aim of experimental work is to form the blank to a hemispherical shape and determine resulted strains. Strain analysis by grid marking is a useful method. The blank was marked with the circle grid pattern using of photochemical etching method before forming process was carried out. After deformation the circle is transferred into ellipse. Circle of 2.5mm diameter have been suggested as a good size in [7, 2]. While the blank is being spine, some grooves appear on the sheet, and the size of grooves depend on tool feed rate and force. It is used from more number of passes and less tool feed rate to reduce the size of grooves and improve the surface quality. If the circle diameter is smaller (than 2.5mm), then the number of places (points) where their strains are measurable, will increase and also the strain curve will be smoother, but because of little variations of the circle dimensions and the effects of grooves on the sheet, strain exact measuring is almost impossible. If the circle with large diameter is selected, then measuring of circle dimensions variations will be simpler and more reliable, but some disadvantages will be appeared such as: obtaining less number of points, being non-smooth strain curve and being more intense curvature effect. Eliminating these difficulties, the circles with medium diameters of 6mm was applied which are arranged according to the pattern of Figure 7. The circles center are tacked place on the concentric orbits shifted 2mm toward each other. The sequence of strain measurement is shown in Figure 7. The shown pattern has all advantages of two previous methods.

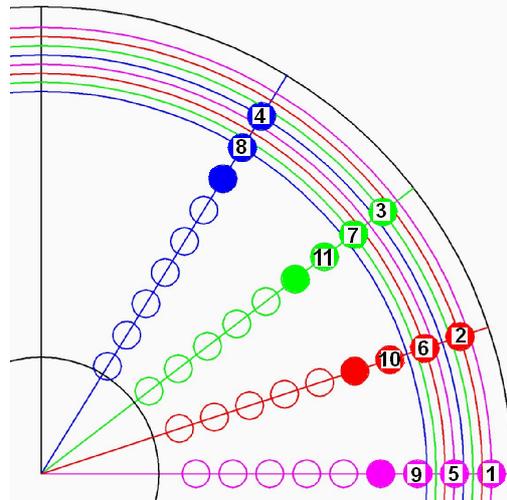


Figure 7: The circle grid pattern marked on the bank surface.

Figure 8 shows strains obtained from measuring the circles pattern variations after spinning. The measurements were made using a Baty R400 optical projector. Unfortunately, due to the small sheet thickness used it was difficult to measure the thickness strain accurately.

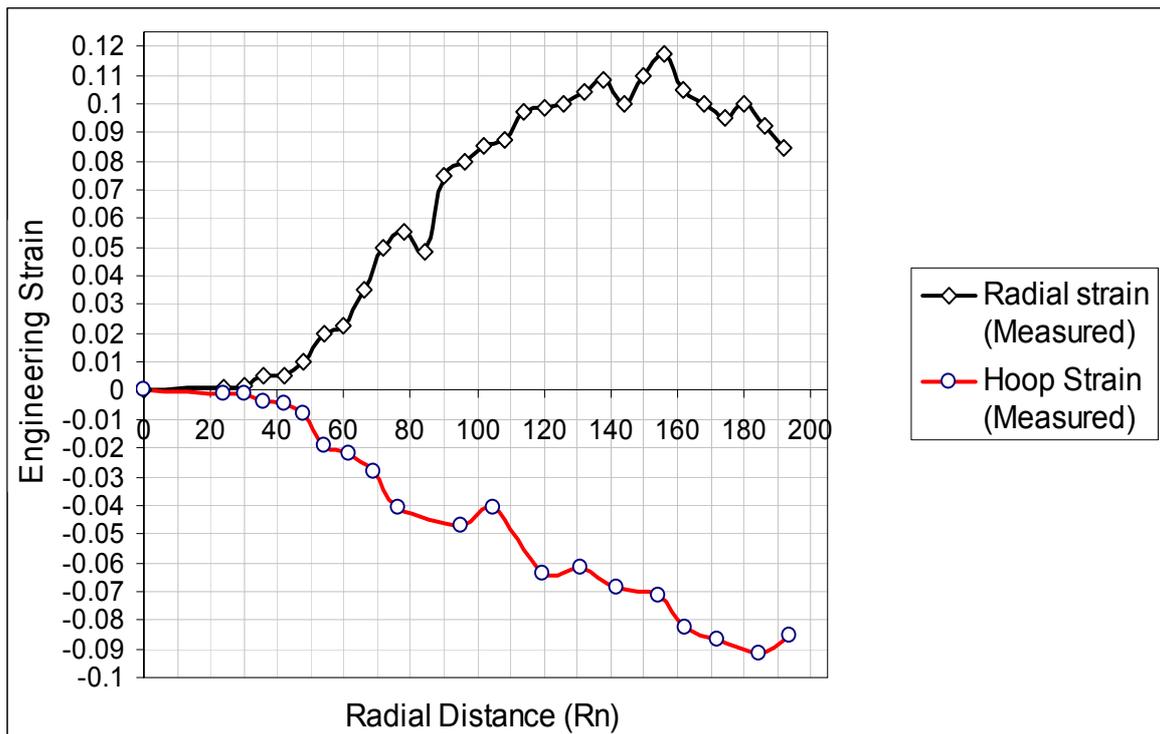


Figure 8: The diagram of measured strains arising from experimental work.



5 Conclusion

Figure 9 shows the measured strain compared to the FE curves presented earlier in Figure 6. The magnitude of radial and hoop strains remain close to the values obtained from FE analysis for spinning process, but the observed strains do not mirror each other thus implying that there is some thickness strain. As it shown in Figure 9, the strains arising from FE simulation and experimental work have good compatibility.

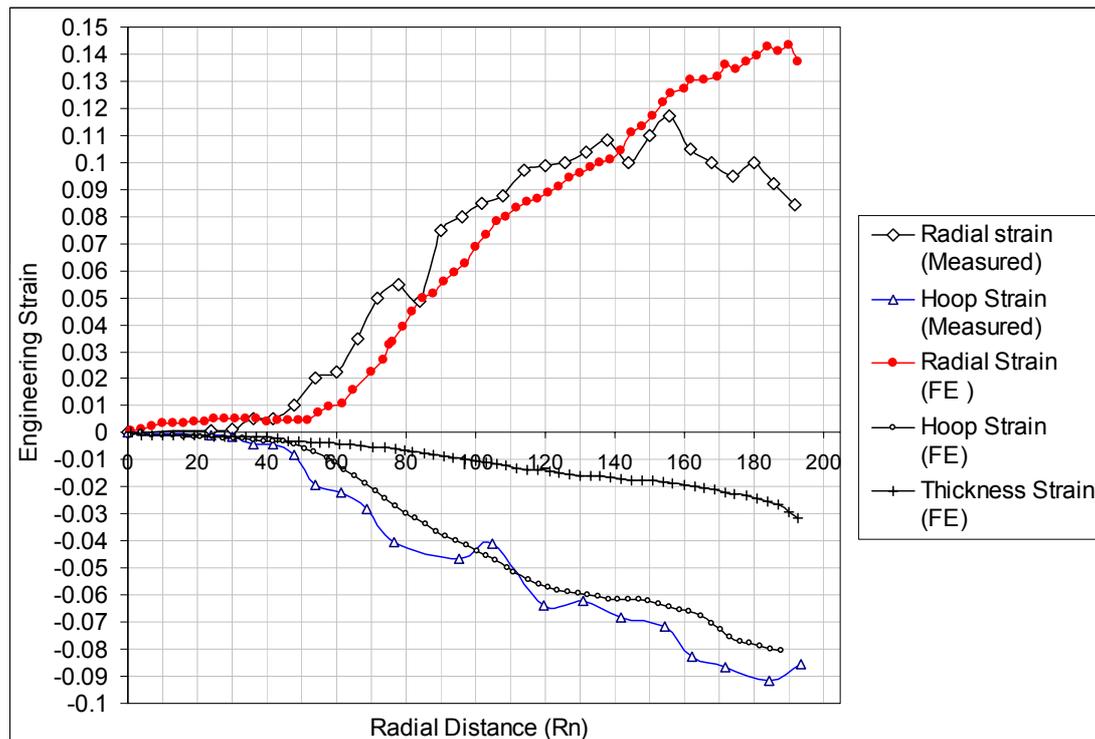


Figure 9: Comparison of strains resulted from FE analysis and experimental work

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