碩士學位論文

The Finite Element Analysis for Shot Peening Process

濟州大學校 大學院

機械工程學科

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The Finite Element Analysis for Shot Peening Process

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Thesis director, Dong-Won Jung, Prof. of Mechanical Engineering

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Date

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SUMMARY

Shot peening process is one of the widely adopted surface strengthening technology in the factory. It has some advantages and disadvantages compared with other processes(casting, welding, stamping, etc). For example the advantages of the shot peening process: process has simple equipment, low cost of doing, not restricted by the shape and location of the parts, easy operation, etc. And the disadvantage is the poor operation condition([1], [2], [3]).

Shot peening process is widely used to improve the mechanical strength, wear resistance, fatigue resistance and corrosion resistance of the parts. And also used to surface extinction, to scale, and eliminate the residual stress of casting, forging, welding, etc. The process consists of impacting the surface of the parts by multiple high velocity shots which induce a layer of the plastic deformation near the surface and work-harden the near surface material. And there has a wide variety of the parameters which are known to influence the effectiveness of the shot peening process which can be principally categorized as shot, target and flow parameters. In practice, however, shot peening process is not described by each of the single mentioned process parameters, but principally by coverage percentage([4], [5], [6]), Almen intensity and type of the used peening media. These are the key parameters for industrial calibration of shot peening process.

The finite element analysis(FEA) is a method which uses the mathematical approximation method to simulate the real physical system(geometry and loading conditions). And based on the simple and interacting elements which are called unit can use a limited number of unknown variables to approach the infinite unknown quantity of the real system. With time, engineer has developed so many finite element software which can be use at some areas, and we can use the finite element to do simulation which can see the condition after the stress and others boundary conditions.

In this paper we will use the finite element analysis software(ABAQUS) to do the simulation for the shot peening process. ABAQUS is a robust finite analysis software for engineering simulation which can solve the problems from the relatively simple linear analysis to many complex non-linear problems([7], [8], [9], [10], [11], [13]). From the simulation in ABAQUS we can get the residual stress near the surface of the plate, and based on the distribution and value to guide the actual production.

Firstly we use the intrinsic component in ABAQUS to do the simulation and find that the intrinsic component is difficult for the definition of the boundary conditions. Because the distributed arrangements and sequences are predetermined by intrinsic component which is far from the random impact model in actual production. In need to get the random impact model we developed a random impact model by python language in ABAQUS, and run the script([12], [14], [15]).

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1.1 The background of shot peening process

Shot peening process is widely used to improve the mechanical strength, wear resistance, fatigue resistance and corrosion resistance of the parts. And also used to surface extinction, to scale, and eliminate the residual stress of casting, forging, welding, etc. Fig.1-1 shows the equipment and operation of the shot peening process in mechanical industry.

Fig.1-1 the equipment and operation of the shot peening process

1-2 .The theory of shot peening strengthening

The shot peening strengthening is the process which balls of the high speed continuously flow to the workpiece’s surface. The flow of the balls looks like so many small hammers hit the metal surface which can produce a very strong plastic deformation near the surface of the workpiece. That means produce the cold hardening layer which is called the surface strengthened layer. Fig.1-2 shows the change between before and after of the shot peening process.

From the point of the stress state, the high residual stress is produced in the strengthened layer. In terms of the structure of the organization there are so many extremely dense dislocations in the strengthened layer, and the shape of dislocations will become polygons which is regular arrangement under the action of the alternating stress and temperature. And so the more tiny grains will be developed in the strengthened layer([16], [17], [18]).

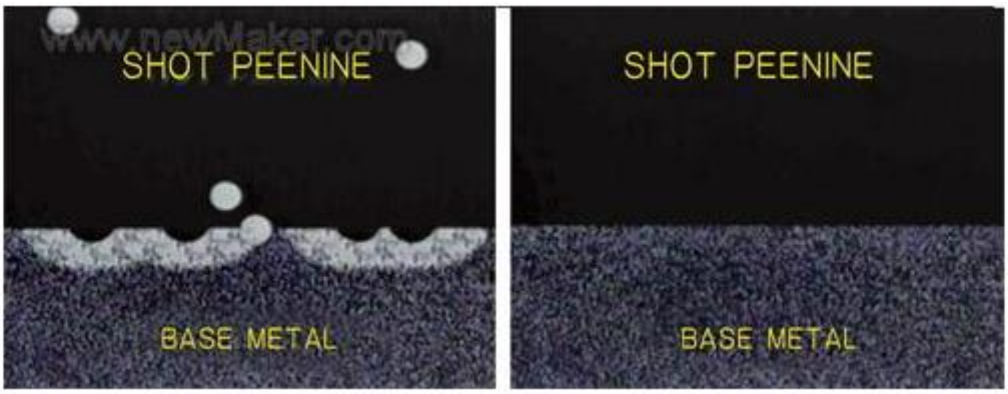


Fig.1-2 shows the change between before and after of the shot peening process.

1-3. The purpose of this paper

In order to avoid the time and money consuming process of trial and error, computational mechanics have been applied to study the mechanical phenomena involved in shot peening process. During this paper we will use the finite element analysis to do the simulation based on the ABAQUS. Using the finite element analysis we want to get the value of residual stress of the surface strengthened layer([18], [19]), and guide the shot peening process in factory to get better quality. The better quality of the production is closely related to value and distribution of the residual stress. After finishing the simulation we will export the value of the residual stress of the different depth in the vertical direction.

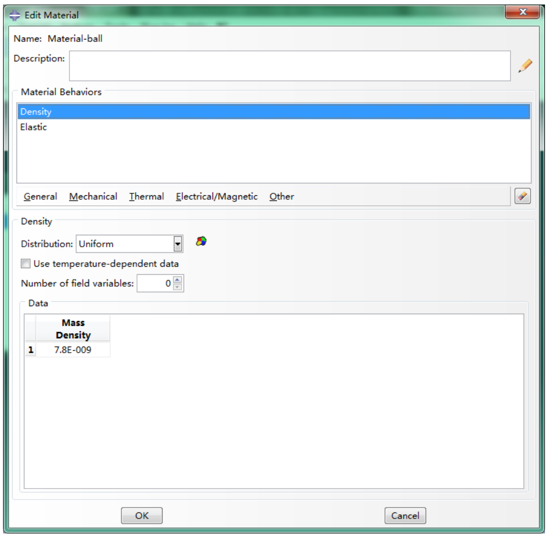
But the random locations and sequences of the balls is difficult to realize in ABAQUS's inherent module. This paper will use the python language to write a unique script which can make the random locations and sequences of the balls true([20], [21], [22]).

2. The limitation of the inherent module for shot peening analysis in ABAQUS

2-1. The material property of the plate and ball in shot peening process

The material data of the plate and ball will input to ABAQUS. The mass density of the ball is 7.8e-9, the young's modulus is 210000, and poisson's ration is 0.31. The type of the balls is discrete rigid which isn't deformation during the simulation.

The mass density of the plate is 7.8e-9, the young's modulus is 210522 , and poisson's ration is 0.31. The type of the plate is deformable and Fig.2-1 shows the true stress-strain cure of this material. The section of plate and ball is solid and homogeneous.



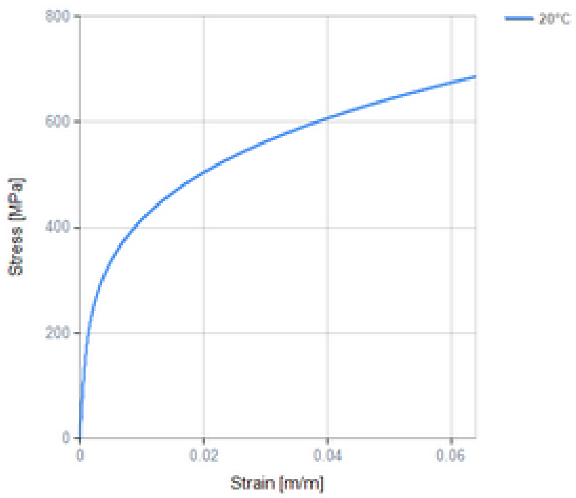


Fig.2-1 The property model in ABAQUS and true stress-strain cure of plate's material.

2-2. The requirements(boundary conditions)of the shot peening process and the limitation of the boundary conditions in ABAQUS

When using the finite element analysis purpose of the simulation must follow the actual. The shot peening process needs the steel balls continuously impact the surface of the plate, and the locations and sequences of the balls are random. The velocity of the balls is 40 mm/s([23], [24], [25]).

But the inherent module in ABAQUS is difficult to realize that random. Fig.2-2 shows the assembly model and the fixed locations and sequences of the balls before shooting.

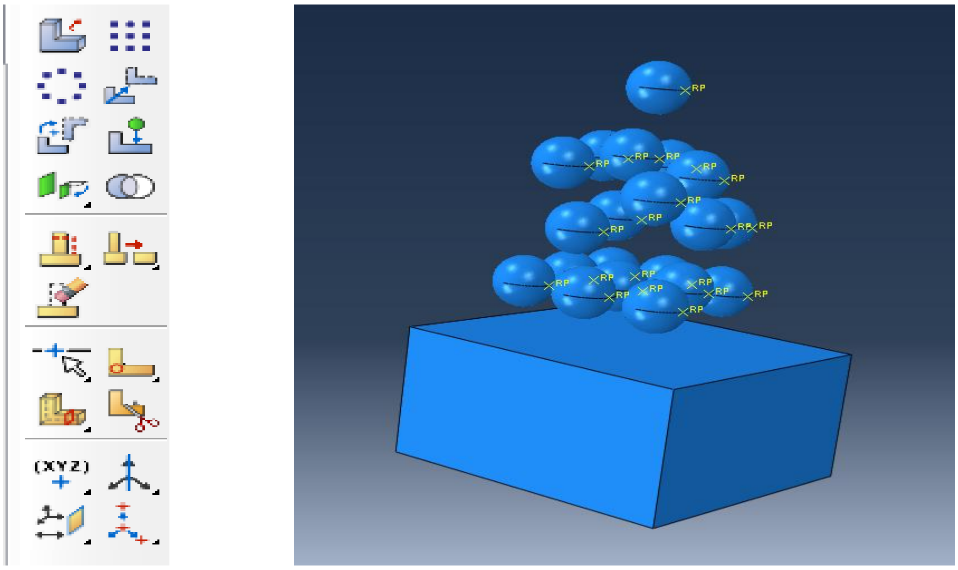


Fig.2-2 The assembly model in ABAQUS and fixed locations and sequences of the balls before shooting.

3. The new approach to realize the random locations and sequences of the balls

3-1. The application of Python language in ABAQUS

Python is a interpreted and object-orientation computer programming language which is invented in 1989 by Guido van Rossum. The grammar of the python is clear and concise, and can easy link with other various modules (especially C/C++)([26], [27], [28], [29], [30], [31]). The design philosophy of the python is elegant, clear and simple. Python is easy to read compared with the other computer language. When we read the python script looks like read English. For the newcomer python is easy to learn because of the very simple documentation.

we can use the python language to write the script. And after finishing the script run the script in ABAQUS that will automatic finish the process in ABAQUS. In this simulation we will finish the modeling and material property of the plate and balls in ABAQUS in inherent module. And the rest of the simulation the python script will finish.

3-2. The principle of Python script to realize the random locations and sequences of the balls

To achieve this goal, a new script has been developed in Python, which chooses a random position in the impact zone for the first shot; then, it simply subtracts the effective dimple area from the impact zone considering new borders for the impact area; thus for the next shot, it chooses a random position in the new impact zone. This approach does not let the distance of two impact centres to be less than the radius of dimple diameter. The procedure continues till the impact zone is completely covered by the effective indentations([32], [33]). Fig.3-2 shows the first three steps of the procedure for choosing the impact centres in an attempt to simulate full coverage([34]).

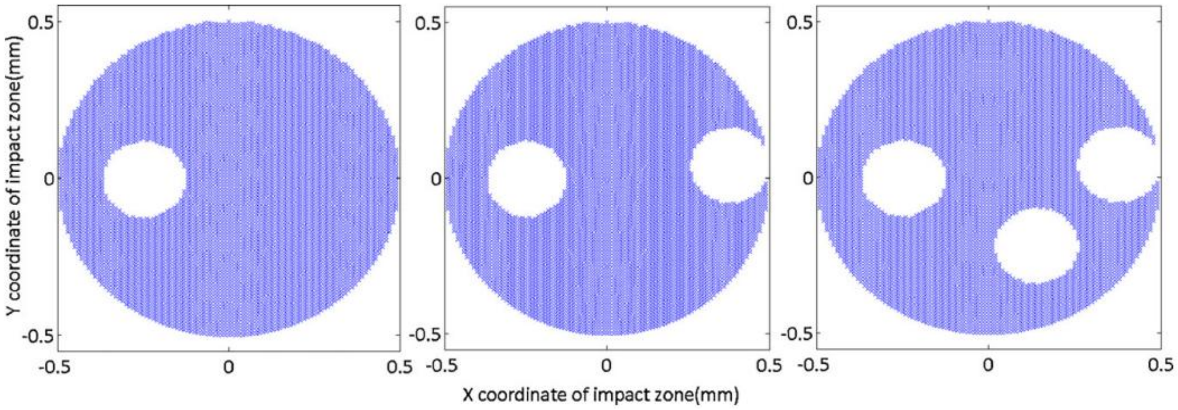


Fig.3-2 Impact pattern generated by the first three successive impacts by Python script.

3-3. The modeling and the Python script for the rest steps(assembly, step, interaction, load, mesh) in ABAQUS

The multiple shot peening is based on two primary parts which are plate and balls. And Fig. 3-3 shows the modeling of the plate and ball in abaqus([35], [36], [37]). The radius of the ball is 0.3mm, and the length of square plate is 3mm. The modeling and the material property will be finished in ABAQUS inherent model, and the others balls will be automatic generated in latter Python script.

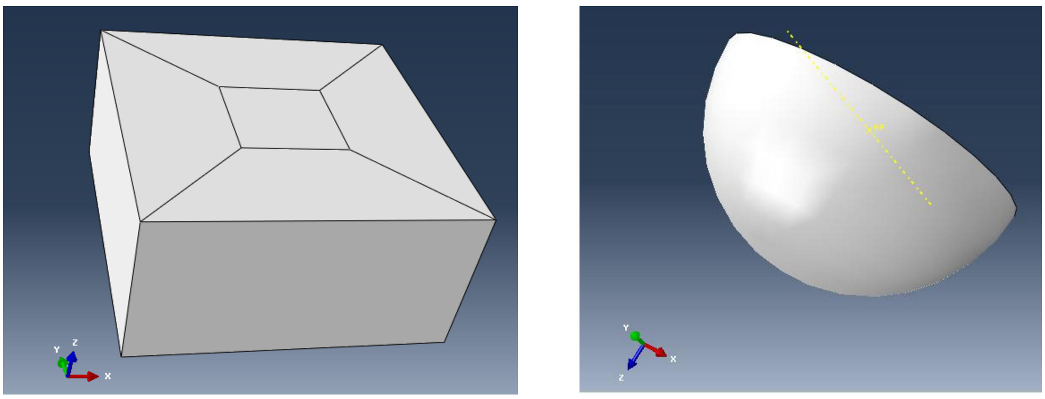


Fig. 3-3 The modeling of square plate and ball in abaqus.

The python script is shown as follow:

- from abaqus import *
- from abaqusConstants import *
- import random
- import math
- import regionToolset
- Nballs = 20 #the number of the ball
- Rball = 0.3 #the radius of the ball
- Velocity = 40.0 #the velocity of the ball
- Rcircle = 0.5 #the radius of the circular impact area
- MinDis = 0.0 #the minimum spacing between the balls， and we don't consider the spacing whose value is zero in this simulation
- #MinDis = 2*Rball/5
- Interval = Rball/2. #the spacing of the steel ball along the direction of impact, and the default value is half of the ball's radius
- xList = []
- yList = []
- for i in range(Nballs):
- x = -0.5 + random.random()
- y = -0.5 + random.random()
- z = -0.35 - i*Interval
- minDis = 100.
- if i!=0 :
- minDis = 100.
- for j in range(len(xList)):
- Dis = math.sqrt((xList[j] - x)**2 + (yList[j] - y)**2)
- if Dis < minDis : minDis = Dis
- while ((x**2 + y**2) >0.25) or (minDis < MinDis):
- x = -0.5 + random.random()
- y = -0.5 + random.random()
- z = -0.35 - i*Interval
- minDis = 100.
- if i!=0 :
- minDis = 100.
- for j in range(len(xList)):
- Dis = math.sqrt((xList[j] - x)**2 + (yList[j] - y)**2)
- if Dis < minDis : minDis = Dis
- while ((x**2 + y**2) >0.25) or (minDis < MinDis):
- x = -0.5 + random.random()
- y = -0.5 + random.random()
- if i!=0 :
- minDis = 100.
- for j in range(len(xList)):
- Dis = math.sqrt((xList[j] - x)**2 + (yList[j] - y)**2)
- if Dis < minDis : minDis = Dis
- xList.append(x)
- yList.append(y)
- BallName = 'Ball-' + str(i+1)
- a = mdb.models['Model-1'].rootAssembly

- p = mdb.models['Model-1'].parts['Ball']
- Instance(name=BallName, part=p, dependent=ON)
- translate(instanceList=(BallName,), vector=(x, y, z))
- s = a.instances[BallName].faces
- side1Faces1 = s[0:1]
- region1=regionToolset.Region(side1Faces=side1Faces1)
- s1 = a.instances['Plate-1'].faces
- side1Faces1 = s1[1:2]+s1[9:11]+s1[15:16]+s1[21:22]
- region2=regionToolset.Region(side1Faces=side1Faces1)
- intName = 'Int-' + str(i+1)
- mdb.models['Model-1'].SurfaceToSurfaceContactExp(name =intName,
- createStepName='Step-1', master = region1, slave = region2,
- mechanicalConstraint=KINEMATIC, sliding=FINITE,
- interactionProperty='IntProp-1', initialClearance=OMIT, datumAxis=None,
- clearanceRegion=None)
- a = mdb.models['Model-1'].rootAssembly
- c1 = a.instances[BallName].cells
- cells1 = c1[0:1]
- region2=regionToolset.Region(cells=cells1)
- r1 = a.instances[BallName].referencePoints
- refPoints1=(r1[7],)
- region1=regionToolset.Region(referencePoints=refPoints1)
- ConstraintName = 'Constraint-' + str(i+1)
- mdb.models['Model-1'].RigidBody(name=ConstraintName, refPointRegion=region1,
- bodyRegion=region2)

- a = mdb.models['Model-1'].rootAssembly
- r1 = a.instances[BallName].referencePoints
- refPoints1=(r1[7],)
- region = regionToolset.Region(referencePoints=(refPoints1,))
- PredefinedName = 'Predefined Field-' + str(i+1)
- mdb.models['Model-1'].Velocity(name=PredefinedName, region=region,
- field='', distributionType=MAGNITUDE, velocity1=0.0, velocity2=0.0,
- velocity3=Velocity, omega=0.0)

4. Results

First we define 20 balls in the multiple shot peening, and have done four times. After 20 balls are finished we will change the number to 40 of ball in python script, and do again. Every time every ball is random by the python script. Every time run the script we will get a different locations and sequences of the balls. That is mean that the residual stress of the strengthened layer. We get the value of the residual stress from different lines in the strengthened layer([38], [39], [40]).

In post-processing two paths are defined to show the residual stress's value every time. The first path is (1368:976:-49, 40, 12313:12265:-1, 314, 3008, 3057, 3106, 3155, 3204, 3253, 3302, 3351,3400) which is a middle line on the surface of the strengthened layer. And the second path is (12249,12298,12347,38415,38366, 38317, 38268, 9946) which is a line perpendicular to the surface. Fig.4 shows the paths as follow([41], [42], [43]):

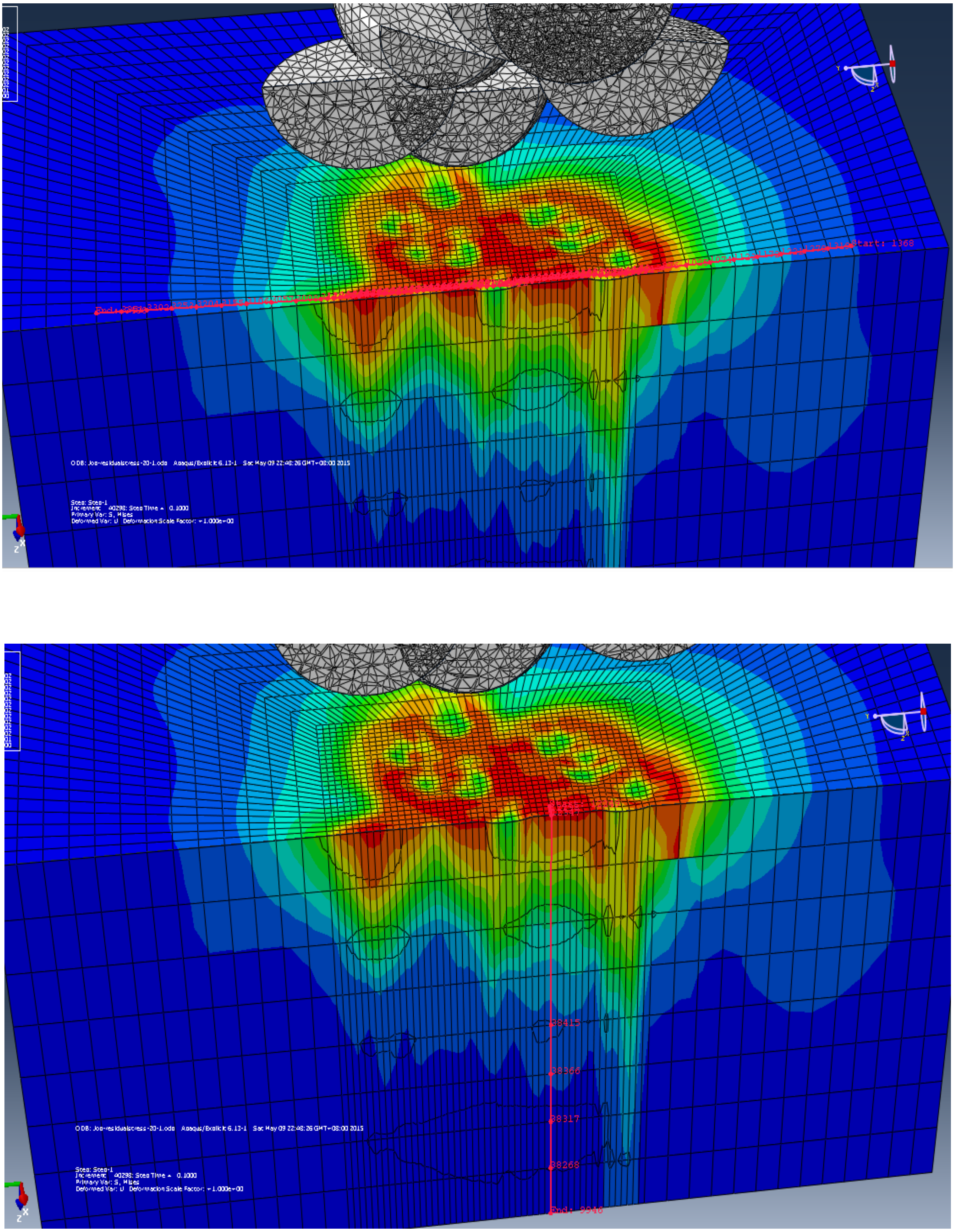


Fig. 4-1 The horizontal path and the vertical path line.

4.1 The first simulation of 20 balls' sequences different times by python script

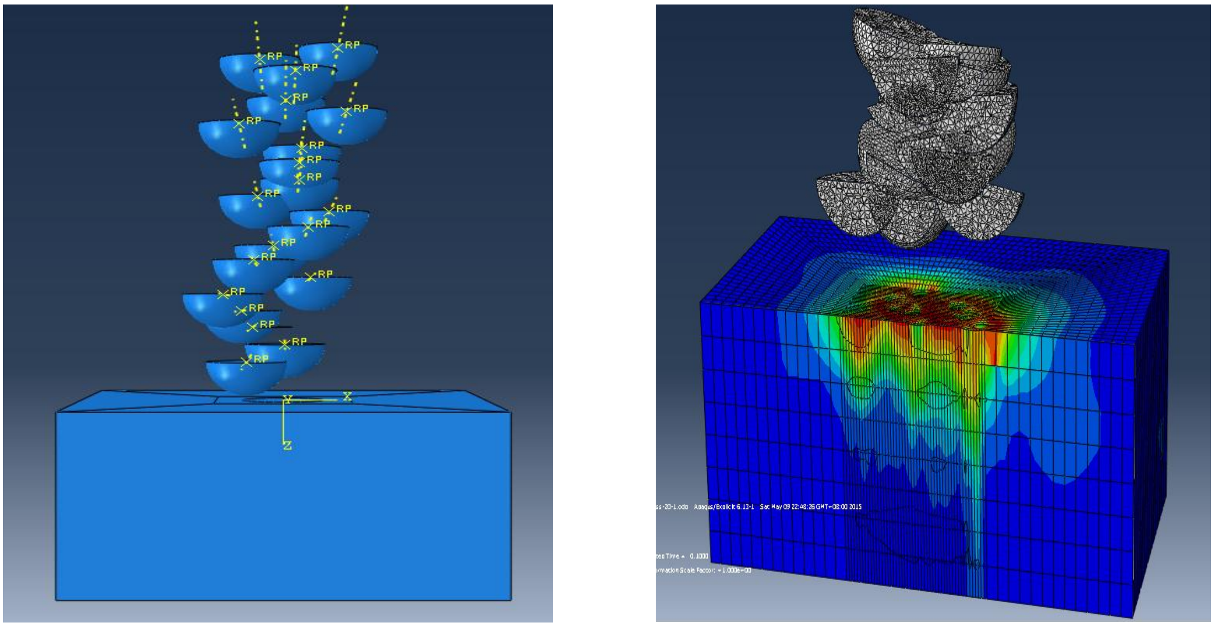


Fig. 4-2 The first time arrangement and residual stress of shot peening process in abaqus.

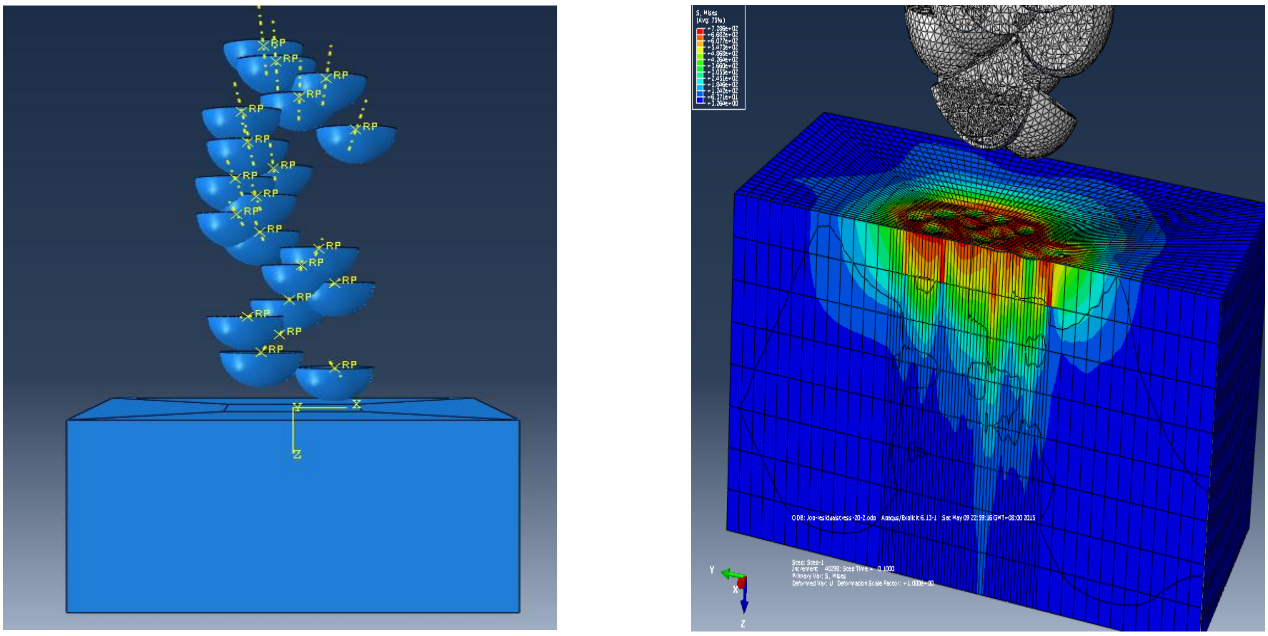


Fig. 4-3 The second time arrangement and residual stress of shot peening process in abaqus.

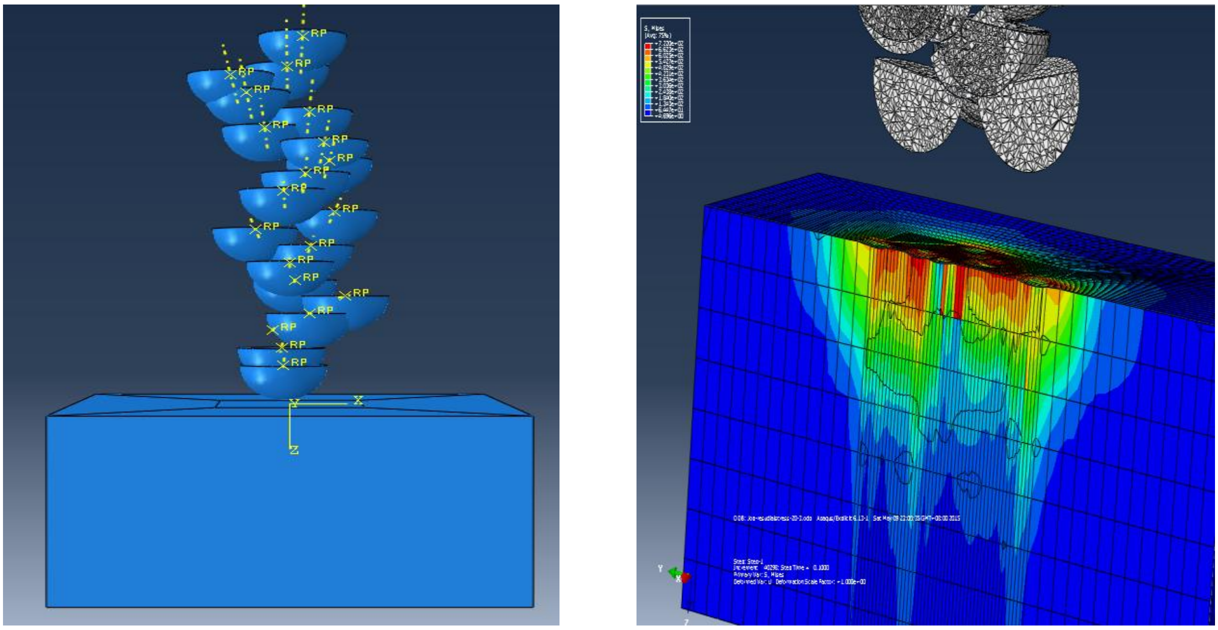


Fig. 4-4 The third time arrangement and residual stress of shot peening process in abaqus.

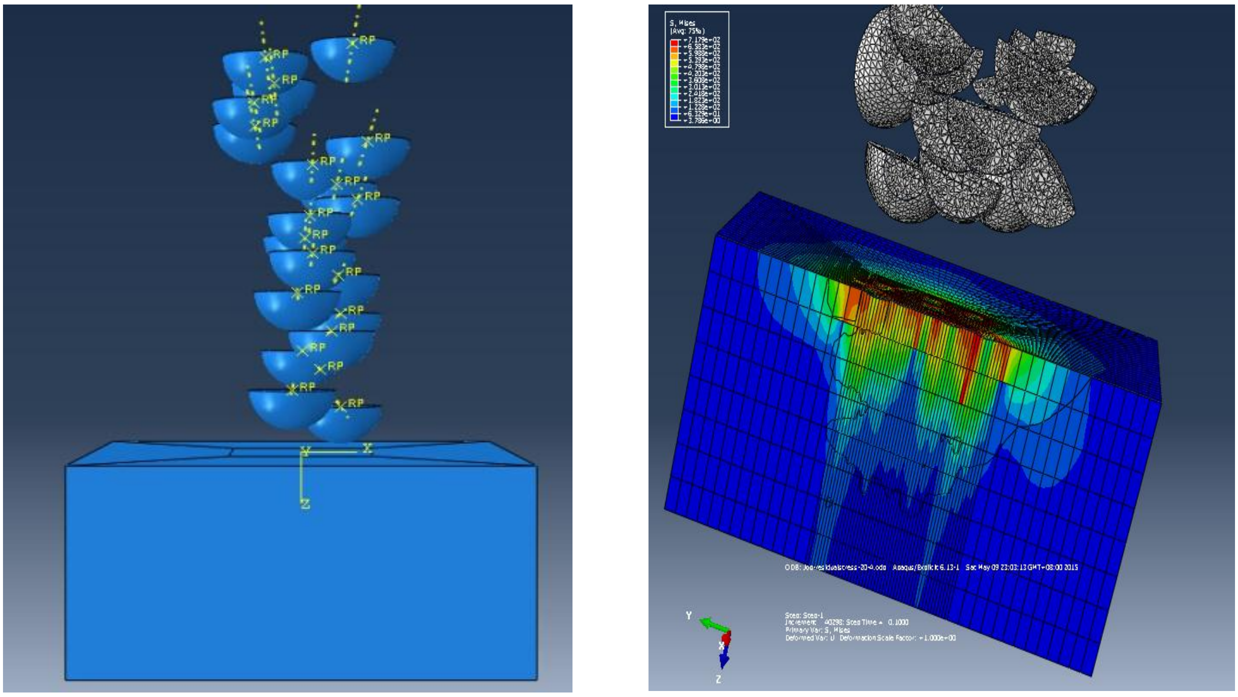


Fig. 4-5 The fourth time arrangement and residual stress of shot peening process in abaqus.

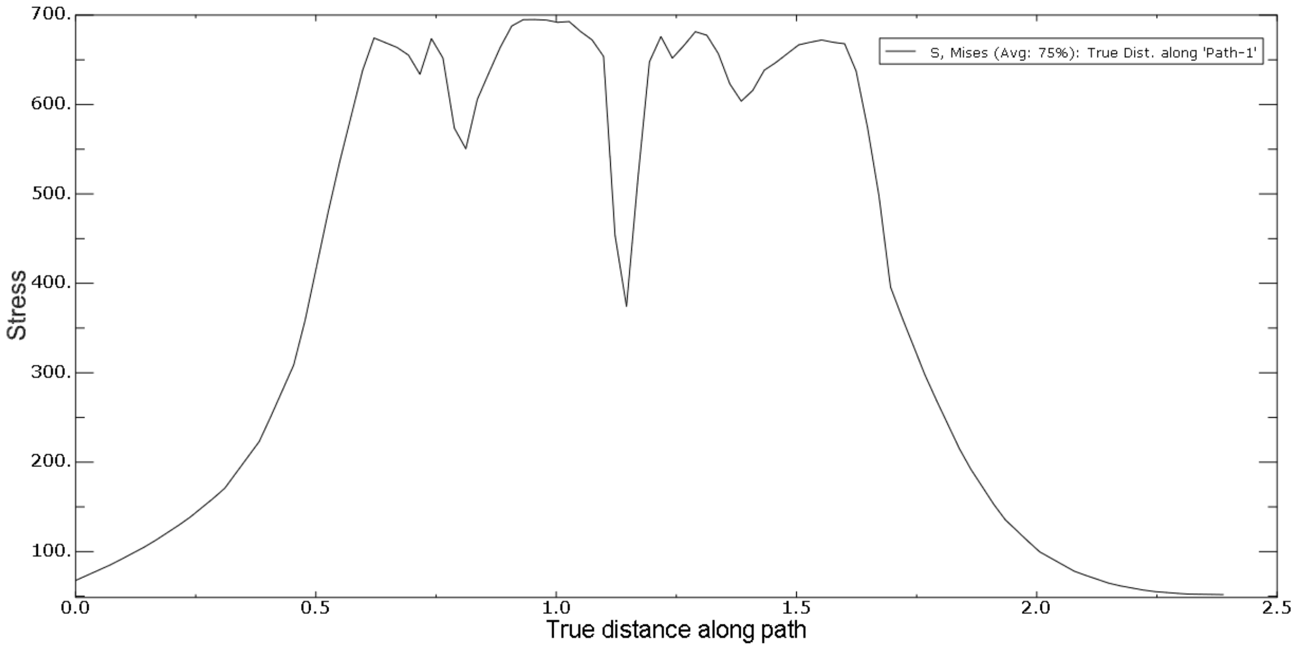


Fig. 4-6 The residual stress curve of the horizontal path first time of 20 balls

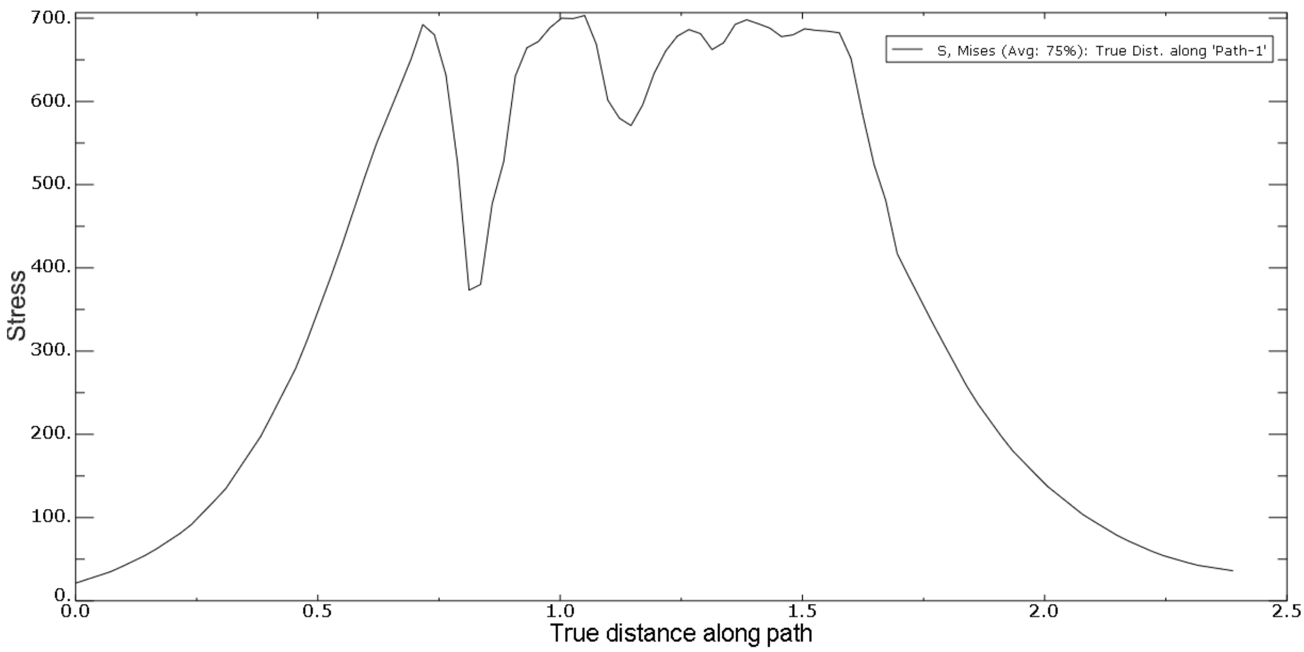


Fig. 4-7 The residual stress curve of the horizontal path second time of 20 balls.

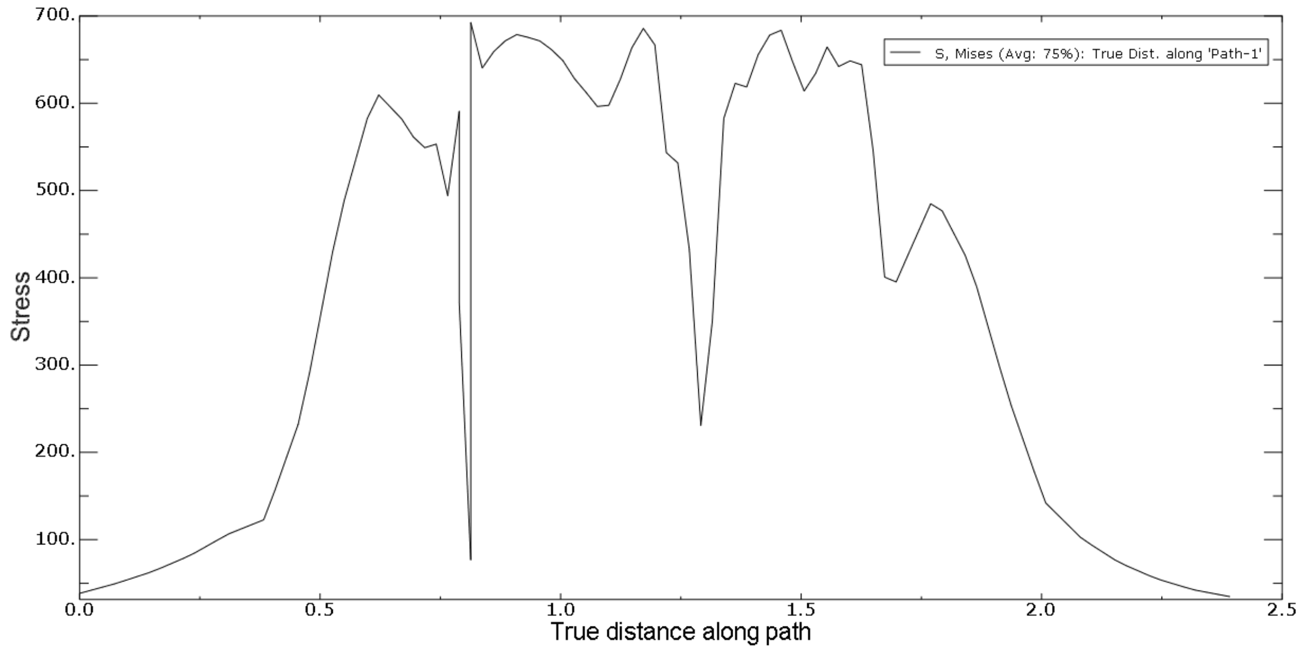


Fig. 4-8 The residual stress curve of the horizontal path third time of 20 balls.

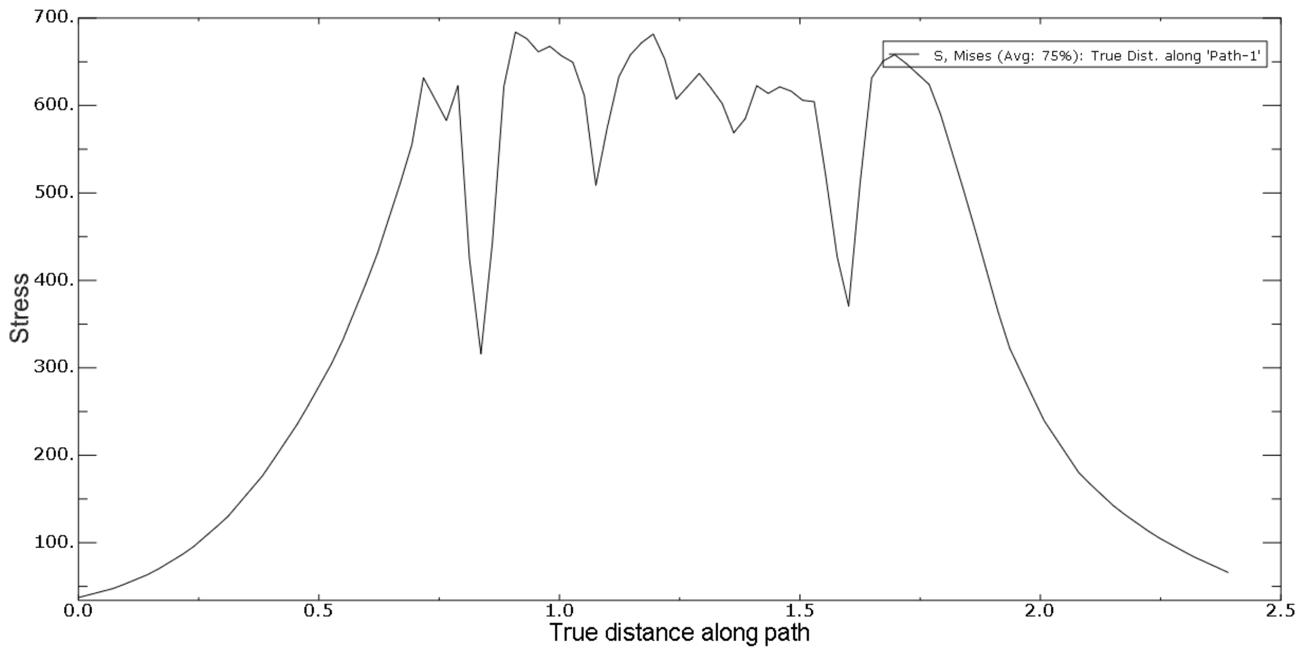


Fig. 4-9 The residual stress curve of the horizontal path fourth time of 20 balls.

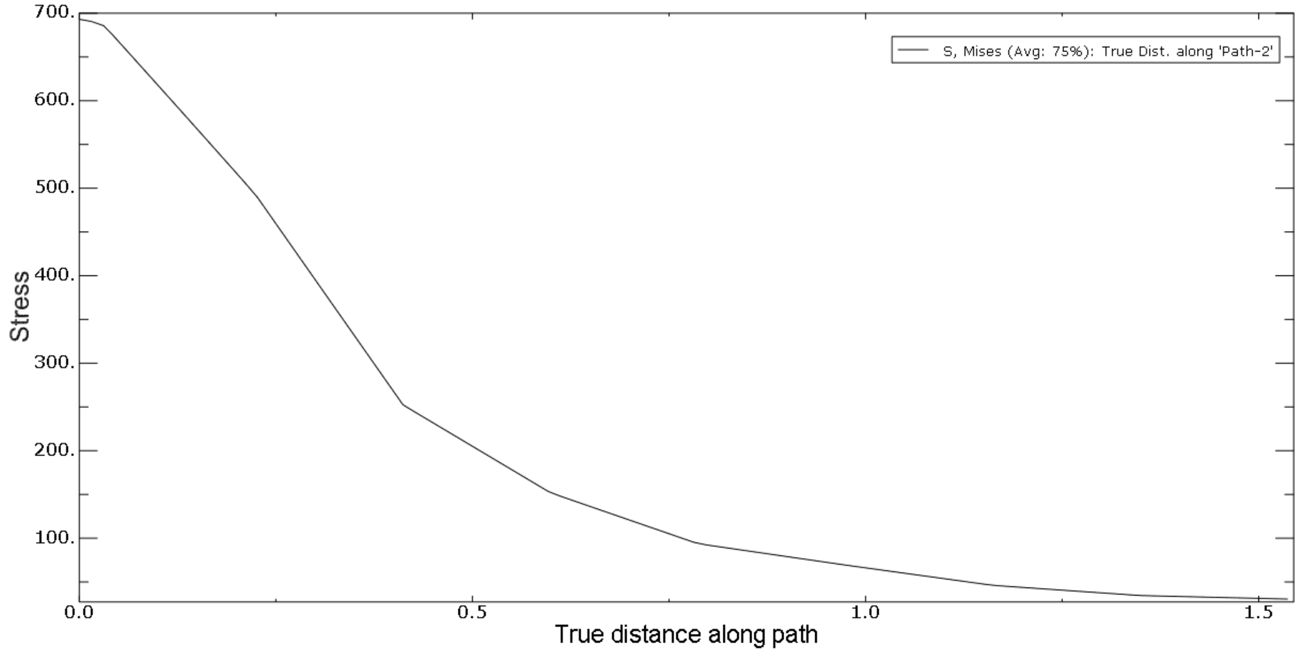


Fig. 4-10 The residual stress curve of the vertical path first time of 20 balls.

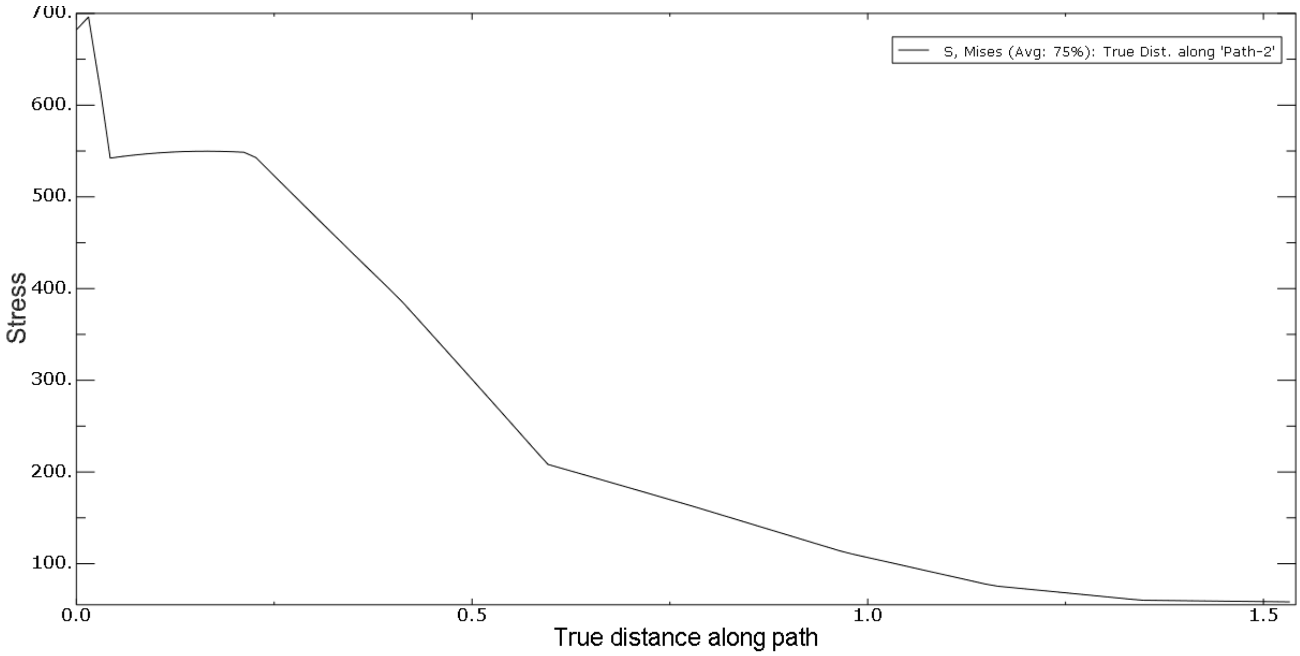


Fig. 4-11 The residual stress curve of the vertical path second time of 20 balls.

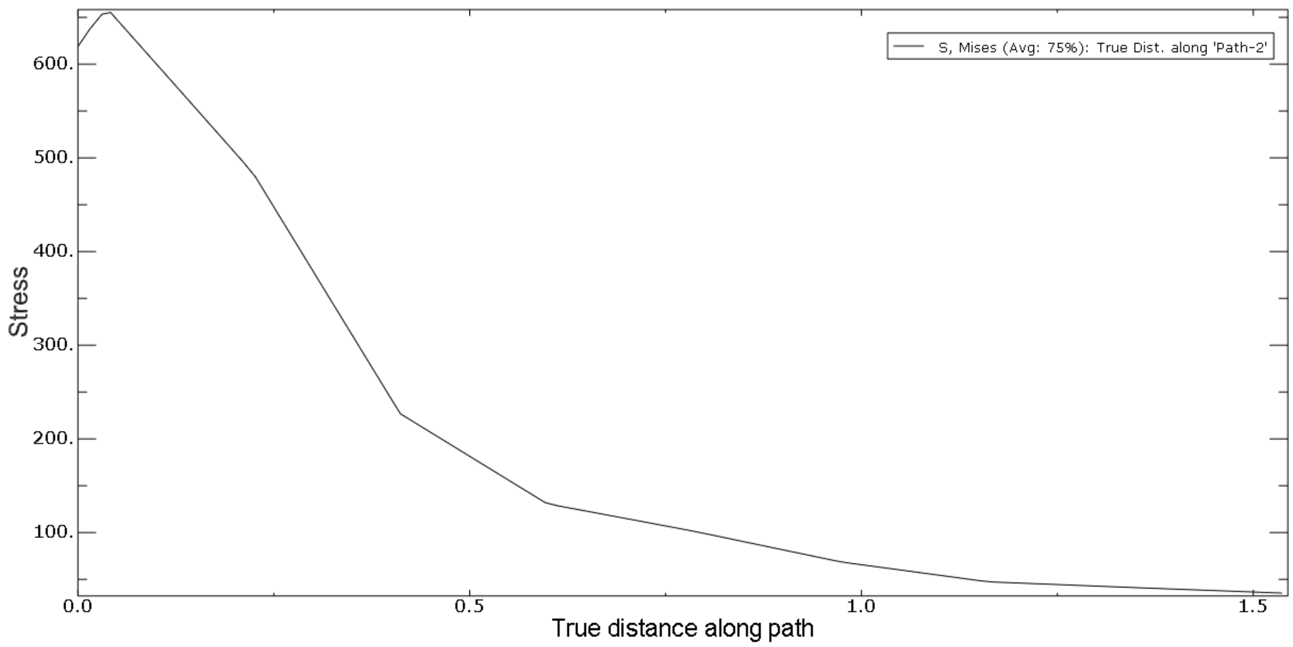


Fig. 4-12 The residual stress curve of the vertical path third time of 20 balls.

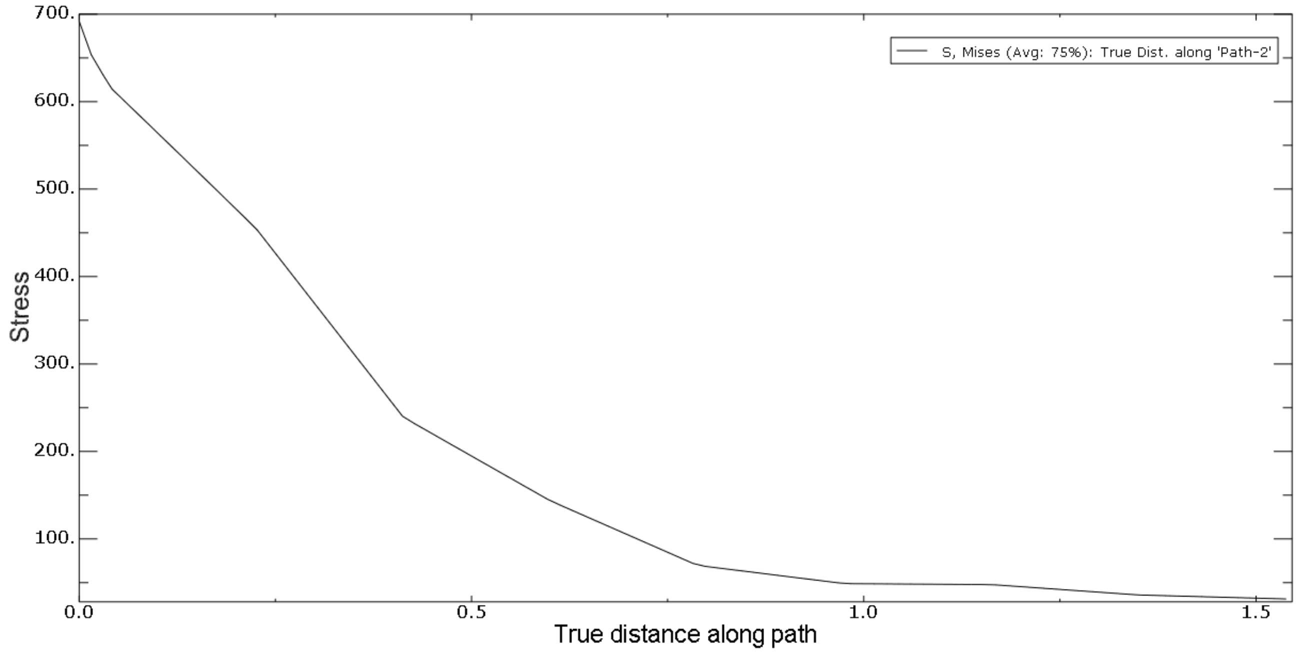


Fig. 4-13 The residual stress curve of the vertical path fourth time of 20 balls.

Table. 4-1 The residual stress value of the horizontal path first time of 20 balls.

X/ True distance	Y/ Residual stress
0	67.6511
0.159253	109.993
0.318507	176.652
0.477761	358.881
0.637013	670.869
0.795983	552.592
0.954624	695.008
1.11342	532.463
1.27184	673.538
1.43109	638.327
1.59034	670.553
1.74956	319.029
1.90881	152.706
2.06807	80.4592
2.22732	56.2398
2.38657	51.8525

Table. 4-2 The residual stress value of the horizontal path second time of 20 balls.

X/ True distance	Y/ Residual stress
0	21.1595
0.15926	59.4037
0.318519	142.108
0.477778	312.769
0.637038	571.916
0.795655	477.995
0.953476	672.028
1.11241	585.561
1.27165	688.776
1.43091	688.058
1.59009	666.101
1.74933	353.257
1.90858	197.452
2.06784	107.68
2.2271	57.4019
2.38636	36.0959

Table. 4-3 The residual stress value of the horizontal path third time of 20 balls.

X/ True distance	Y/ Residual stress
0	38.3798
0.159493	65.1515
0.318986	108.517
0.478479	291.863
0.637927	600.324
0.79674	692.627
0.79674	76.7709
0.955597	671.444
1.11508	614.346
1.27409	367.179
1.43272	678.089
1.59116	640.842
1.74942	465.013
1.90875	297.394
2.06824	107.139
2.22773	56.7534
2.38722	34.6575

Table. 4-4 The residual stress value of the horizontal path fourth time of 20 balls.

X/ True distance	Y/ Residual stress
0	37.2336
0.159412	67.5747
0.318825	135.096
0.478237	257.293
0.63765	457.774
0.796773	565.664
0.955026	661.399
1.11403	626.164
1.27296	635.559
1.43237	613.837
1.59116	351.736
1.74999	632.063
1.9094	363.805
2.06881	186.837
2.22823	110.693
2.38764	65.9278

Table. 4-5 The residual stress value of the vertical path first time of 20 balls.

X/ True distance	Y/ Residual stress
0	693.115
0.0742013	619.499
0.176958	516.093
0.279714	390.676
0.38247	259.08
0.485226	200.099
0.587982	147.95
0.690739	116.058
0.793495	89.6965
0.896251	76.3173
0.999007	63.2534
1.10176	50.5385
1.20452	41.9347
1.30728	35.5472
1.41003	32.617
1.51279	30.421

Table. 4-6 The residual stress value of the vertical path second time of 20 balls.

X/ True distance	Y/ Residual stress
0	682.001
0.0792384	547.65
0.181671	549.087
0.284103	476.734
0.386535	390.485
0.488967	292.45
0.591399	204.48
0.693831	178.998
0.796263	152.922
0.898695	126.102
1.00113	102.679
1.10356	82.7601
1.20599	70.2912
1.30842	61.6445
1.41086	59.3737
1.51329	58.402

Table. 4-7 The residual stress value of the vertical path third time of 20 balls.

X/ True distance	Y/ Residual stress
0	618.798
0.0745089	601.932
0.177232	505.021
0.279956	374.069
0.382679	233.619
0.485402	176.653
0.588126	128.625
0.690849	112.586
0.793573	95.9102
0.896296	77.9731
0.999019	63.0522
1.10174	51.4478
1.20447	45.1783
1.30719	41.7688
1.40991	38.5477
1.51264	35.3664

Table. 4-8 The residual stress value of the vertical path fourth time of 20 balls.

X/ True distance	Y/ Residual stress
0	692.077
0.0741004	565.466
0.17693	475.995
0.279759	364.449
0.382589	246.219
0.485418	189.782
0.588248	138.8
0.691077	98.3153
0.793906	66.3667
0.896736	54.9261
0.999565	48.5765
1.10239	47.9586
1.20522	43.5306
1.30805	37.0233
1.41088	33.8264
1.51371	56.7534

4.2 The second simulation of 40 balls' sequences different times by python script

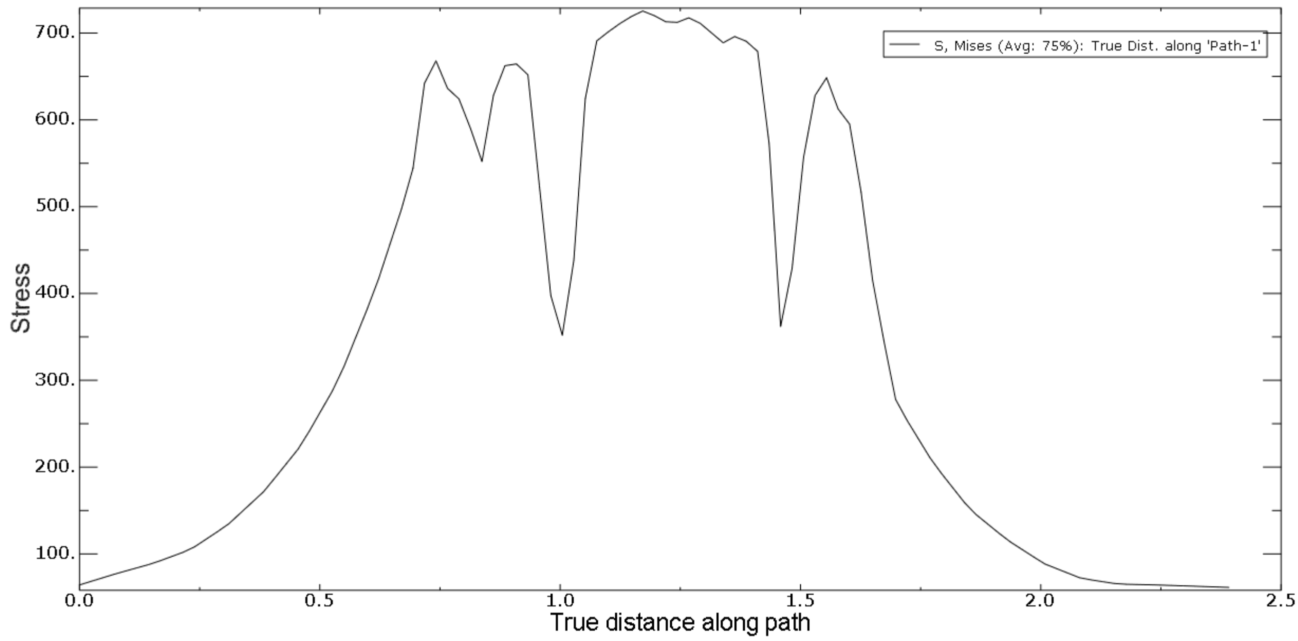


Fig. 4-14 The residual stress curve of the horizontal path first time of 40 balls.

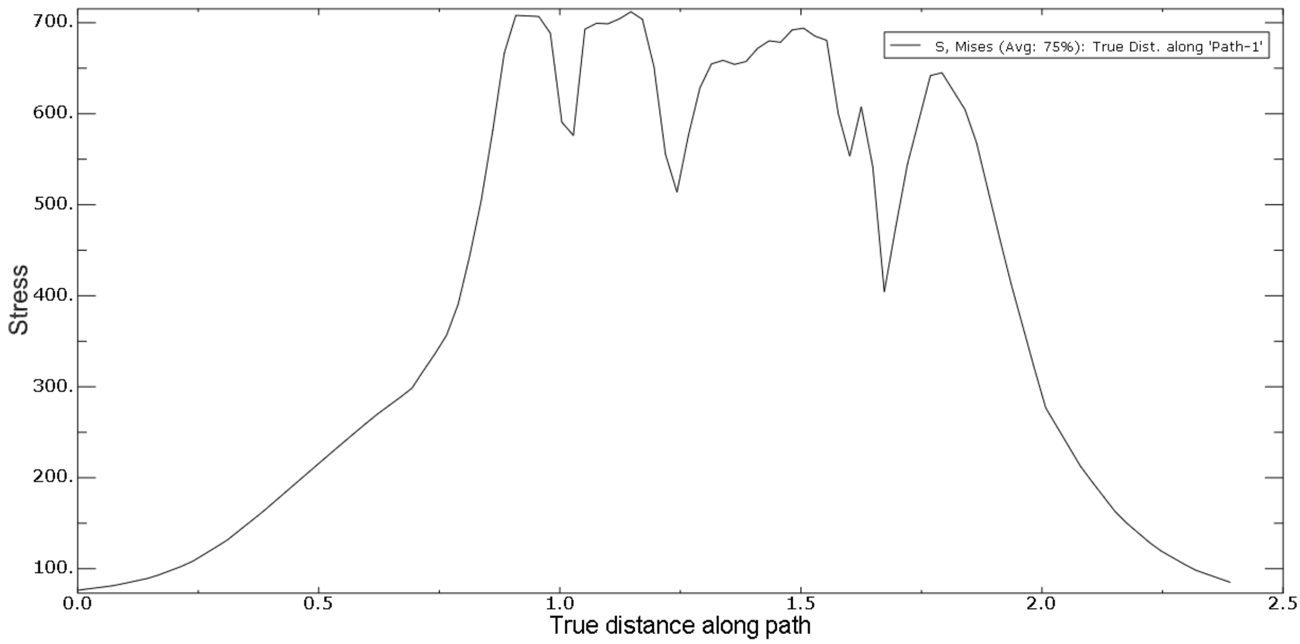


Fig. 4-15 The residual stress curve of the horizontal path second time of 40 balls.

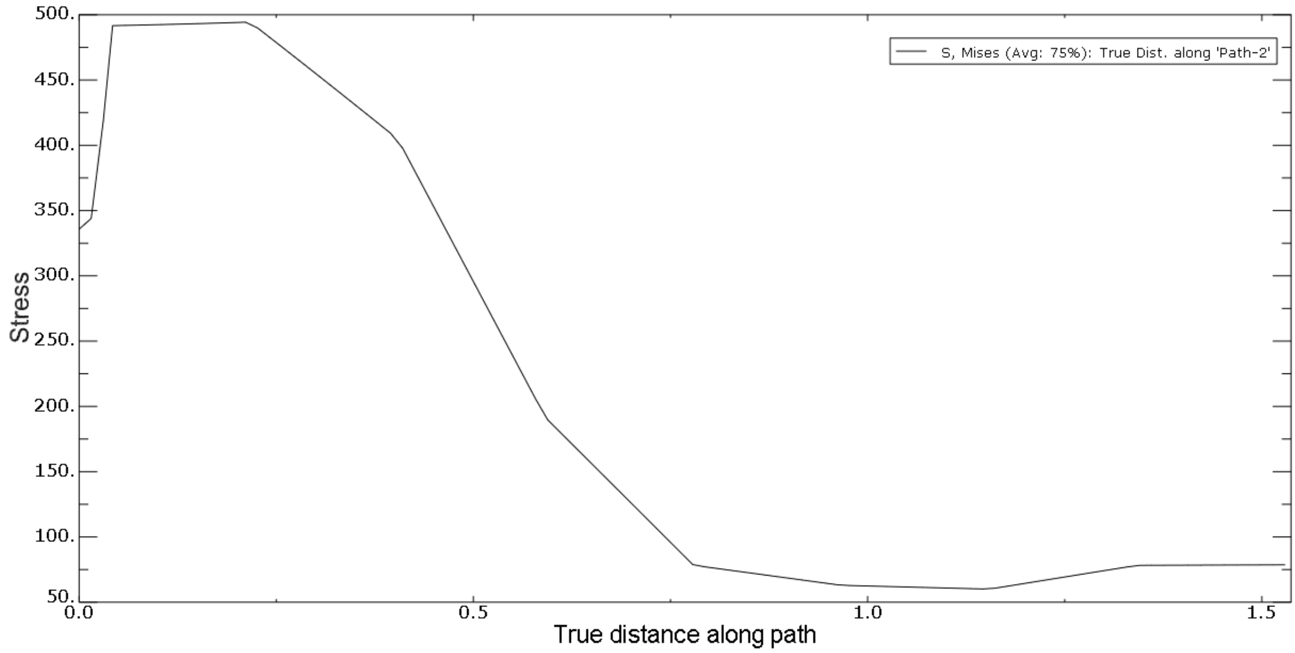


Fig. 4-16 The residual stress curve of the vertical path first time of 40 balls.

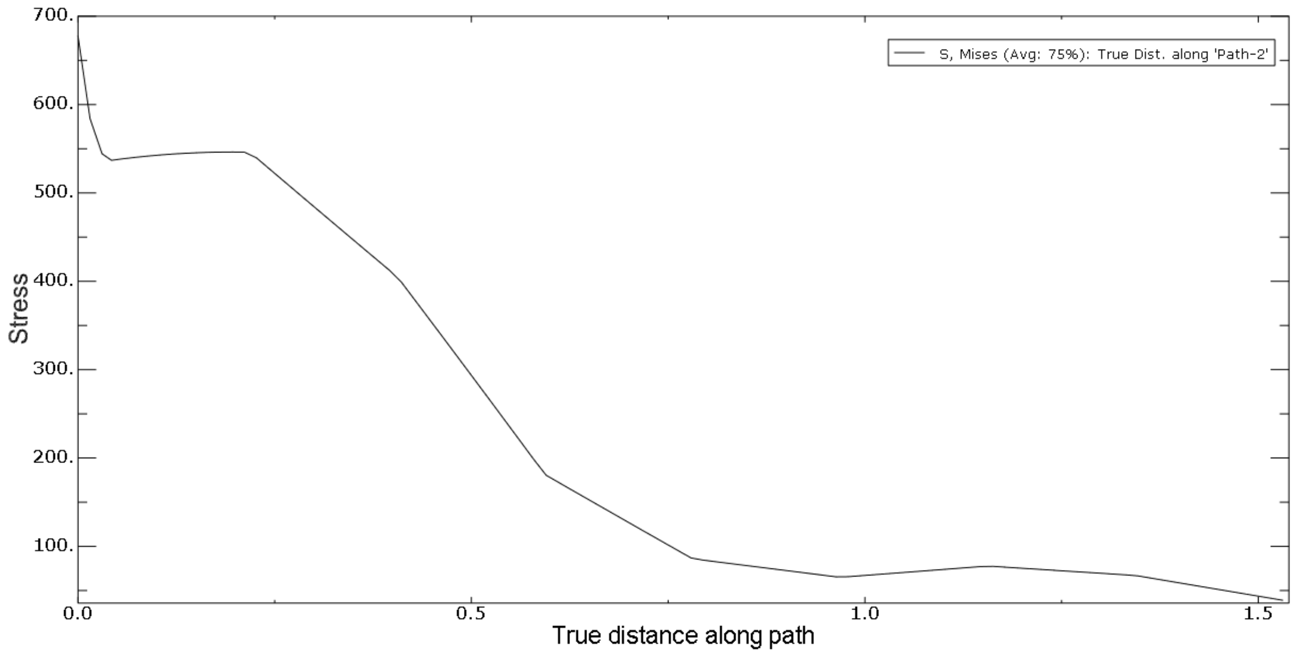


Fig. 4-17 The residual stress curve of the vertical path second time of 40 balls.

Table. 4-9 The residual stress value of the horizontal path first time of 40 balls.

X/ True distance	Y/ Residual stress
0	64.2469
0.159513	90.382
0.319027	138.9
0.47854	241.721
0.638053	443.375
0.797399	615.241
0.954643	524.565
1.11281	707.68
1.27186	718.505
1.43087	572.622
1.58977	604.108
1.74925	224.982
1.90877	123.726
2.06828	74.2934
2.22779	64.3418
2.38731	61.3844

Table. 4-10 The residual stress value of the horizontal path second time of 40 balls.

X/ True distance	Y/ Residual stress
0	76.3346
0.15943	91.4433
0.318861	135.096
0.478291	205.71
0.637721	276.16
0.797123	407.042
0.956551	706.787
1.11494	702.251
1.27287	602.629
1.43206	680.077
1.59049	547.197
1.74924	609.316
1.90861	463.4
2.06804	219.994
2.22747	125.212
2.3869	85.041

Table. 4-11 The residual stress value of the vertical path second time of 40 balls.

X/ True distance	Y/ Residual stress
0	335.669
0.0757347	492.39
0.177918	494.097
0.280102	453.542
0.382285	403.576
0.484468	287.17
0.586652	180.444
0.688835	118.845
0.791019	75.4315
0.893202	67.0704
0.995385	62.1349
1.09757	60.5398
1.19975	66.672
1.30194	76.5955
1.40412	78.4111
1.5063	78.6298

Table. 4-12 The residual stress value of the vertical path first time of 40 balls.

X/ True distance	Y/ Residual stress
0	677.906
0.0765831	542.548
0.178894	546.296
0.281205	481.8
0.383516	405.056
0.485827	283.842
0.588139	172.583
0.69045	120.457
0.792761	82.1196
0.895072	70.6708
0.997383	68.4167
1.09969	75.3767
1.20201	73.8293
1.30432	68.0173
1.40663	54.2733
1.50894	38.94

5. Summary and conclusions

An inclusive study has been performed on the definitions, requirements, theoretical, practical and eventually computational approaches that are available in the paper for the shot peening process. The following results can be drawn:

The study reveals several multiple impacts at identical points that from one point of view correspond to the existing standard definitions, but on the other hand require high computational costs. So we using the finite element analysis to do simulation in computer which can avoid the time and money consuming the process of trial and error. From the horizontal path we found three points, and saw the different values of the residual stress([44], [45]). Three points are 0.159, 1.113, 2.068 in the horizontal path. First point(0.159) value of the 20 balls' residual stress are 109.993, 59.4037, 65.1515, 67.5747. The residual stress value of the second point(1.113) are 532.463, 585.561, 614.346, 626.164. Third point's residual stress value are 80.4592, 107.68, 107.139, 186.837. And we also found three points in the vertical path(0.17, 0.69, 1.51). The values of residual stress of first point(0.17) are 516.093, 549.087, 505.021, 475.995. Second point(0.69) are 116.058, 178.998, 112.586, 98.315. Third point(1.51) are 30.421, 58.402, 35.366, 56.753.

Then change the number of the 20 balls to 40 balls and do the simulation again. From the finite element analysis in abaqus we can get the value of the residual stress in horizontal and vertical path. In this simulation we just done two times of the shot peening process, and output the value three points in horizontal and vertical path. Horizontal path: value of the first point(0.159) are 90.382 and 91.4433. Second point are 707.68 and 702.251. Third point are 74.293 and 219.994. Vertical path: residual stress value of the first point(0.17) are 494.097 and 546.296. Second point are 118.845 and 120.457. Third point(1.51) are 78.6298 and 38.94. Because using the python script we can realize the random locations and arrangements of steel balls which is so closed to the experiment in factory. And from the finite element analysis simulation we can guide the actual production in the factory. For example we change the number of the balls and velocity, and also we can change the material of the balls to get better quality of the shot peening process([46]).

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