Experimental report

15/05/2019

Proposal: 1-04-147

Council: 4/2018

Title: Study on residual stresses in tubewelds out of the a Ni-based superalloy Alloy 617 occ welded by Laser-Multi-Pass-Narrow-Gap-Welding (Lase

Research area: Materials

This proposal is a new proposal

Main proposer: **Benjamin KESSLER**

Experimental team: Sandra CABEZA

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Samples: Tube with an outer diameter of 350 mm and a wall thickness of 36 mm

Instrument	Requested days	Allocated days	From	To
SALSA	4	3	26/09/2018	29/09/2018

Abstract:

Current ecological necessities and political developments led to the “energy transition” which will change future power generation. However, highly efficient thermal power plants are still needed and the enhancement of their efficiency helps to achieve the global climate protection goals. For this reason, research focuses on advanced ultra-supercritical (A-USC) power plants running with importantly increased steam temperature. Increasing the working temperature of turbines results in tougher requirements on the materials e.g. high-temperature stress rupture strength, oxidation behaviour, structure stability in long-time. One of the most promising candidates to meet these challenges is the Ni-based super-alloy Alloy 617 and its further improvements Alloy 617B or Alloy 617 occ.

Laser welding is the preferable technique for precise welding. It can potentially been used for the manufacturing of e.g. turbine shafts, super heater tubes, fittings or flanges. Scientists at Fraunhofer IWS [3] developed the Laser-Multi-Pass-Narrow-Gap (Laser-MPNG) welding technique. It overcomes limitations of laser welding by oscillating the laser beam between the two side walls of the sea

Study on residual stresses in tube weldings out of the a Ni-based superalloy Alloy 617 occ welded by Laser-Multi-Pass Narrow-Gap-Welding (Laser-MPNG)

 # 1-04-147

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Test Material and Investigated Samples

The test material is Alloy 617occ, which is a promising candidate for future HT/HP processes. Alloy 617 occ is melted and re-melted only in vacuum and an optimized chemical composition which leads to enhanced HT properties as well as improved weldability. Table 1 includes the chemical composition of Alloy 617occ test material.

Table 1: Chemical composition in weight % of test material Alloy 617 occ

Ni	Cr	Co	Mo	Ti	Al	Fe	Mn	Si	C	P	S	V	Nb	B
bal.	21,88	**11,49**	8,47	0,43	1,21	0,66	0,34	0,06	0,056	0,012	0,008	0,3	0,17	0,004

The welding experiments and subsequent residual stress measurements were carried out on tubular elements. Figure 1 shows 2 cross sections to illustrate the microstructure. It shows that there is a pronounced texture with large grain (>100 µm, few carbides) and small grain (<100 µm, many carbides). Large grains are desired for improved creep resistance.

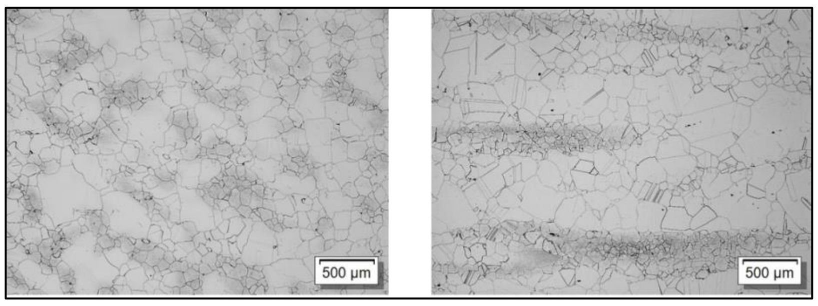

Figure 1: left: Cross section transversal to pipe axis, right: Cross section in pipe axis

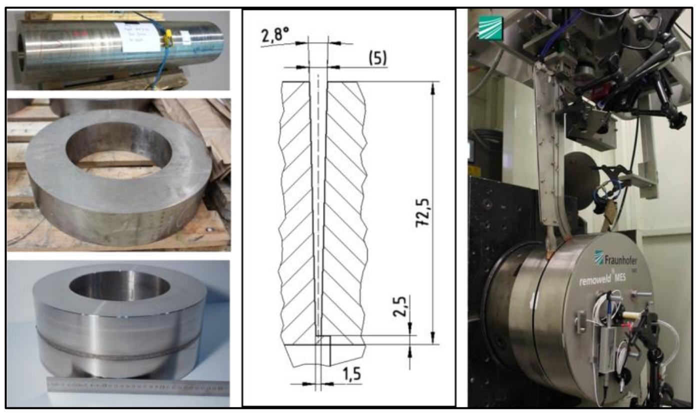

Figure 2: Overview – left: pipe and pipe elements; middle: weld seam preparation; right: experimental set-Up.

The samples were produced by Laser-Multi-Pass Narrow-Gap-Welding (Laser-MPNG) with an ultra-narrow gap using an oscillated laser beam to melt the joining partners and the filler material. Figure 2 shows on the left side the pipe, the prepared pipe elements and a weld sample, in the middle the ultra-narrow gap preparation and on the right side the experimental set-up.

Two small samples were then extracted from the finished weld sample. One of these samples was subjected to a subsequent heat treatment for 3 hours at a temperature of 980 °C. Figure 3 shows the two investigated samples.

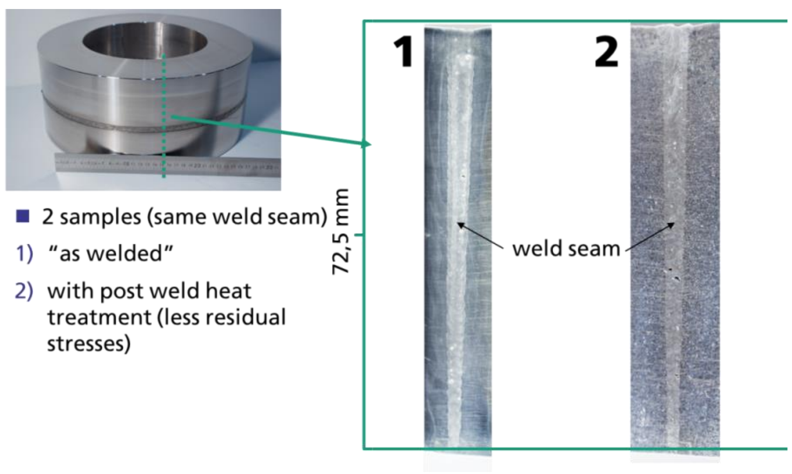

Figure 3: Investigated Samples

Deviation from the originally proposed Sample

Due to the further development of the welding procedure between application and execution, the original sample geometry (sample with outer diameter of 350 mm and a wall thickness of 36 mm (Figure with a maximum height of 40 mm) was changed. Therefore, 2 smaller samples from one weld sample were examined. On the one hand the aim was to reflect the current state of development (72.5 mm wall thickness and a height of ~10mm) and on the other hand the aim was to characterize the influence of the heat treatment. Because 2 complete weld samples can never be joined with exactly the same welding parameters due to component tolerances. It was important to take the samples "as welded" and "with PWHT" from a weld sample.

Experiment Execution

The set up at SALSA and sample orientation for the different strain components is shown in Fig.4. The instrumental gauge volume chosen was 0.6 (horizontal)x2(vertical) mm^2 for the incoming beam, and 0.6mm for the scattered. Due to the coarse grain size the hexapod was also oscillating ±5° in order to increase the statistics. About 20min per point were necessary to achieve a sound peak intensity.
The scanning strategy consisted in 2 lines at different heights of the weld (18 and 54 from bottom). A width of ±10mm from the centre of the weld was characterized with asymmetric pitch (overlapping points in the HAZ and fusion zones). As reference, a point in the base material was taken (far field at 50mm from the weld).

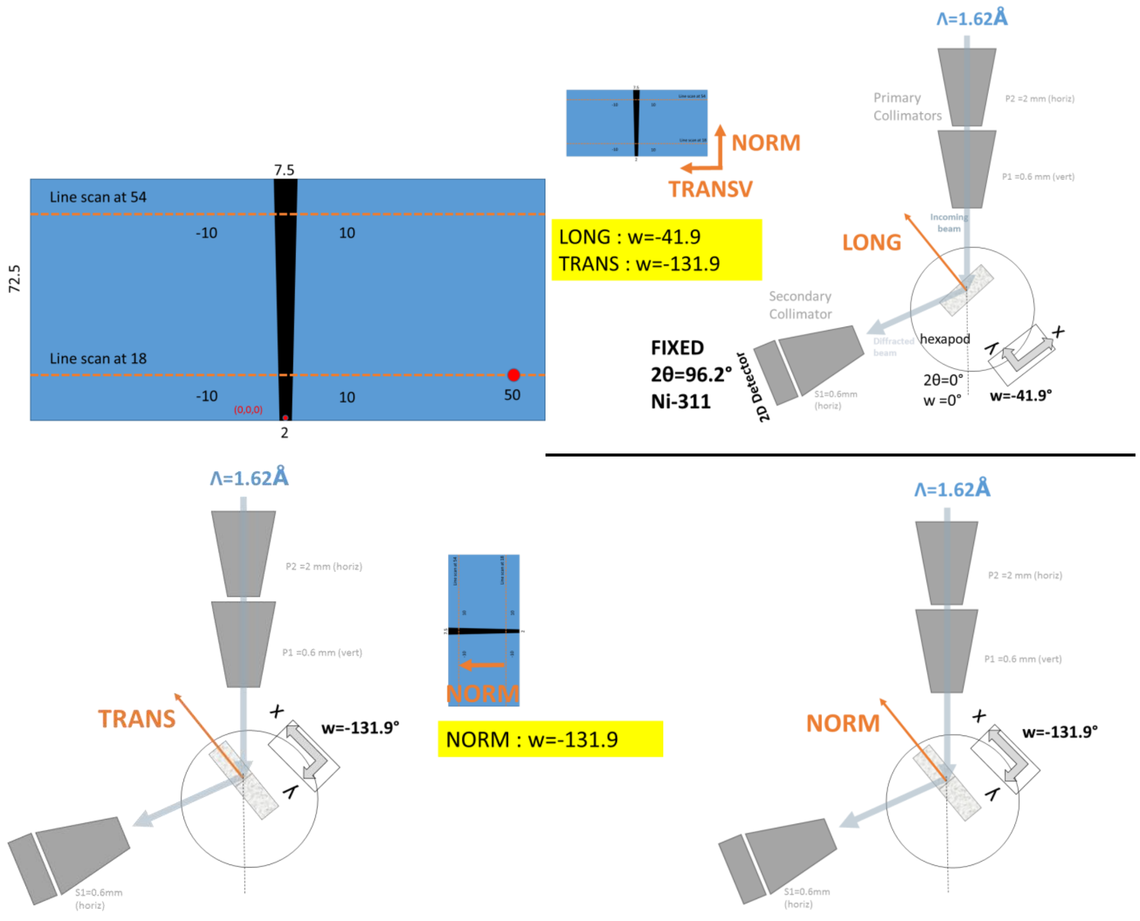

Figure 4. Sample and set ups at SALSA for scanning the three principal strain components: Longitudinal (LONG), transversal (TRANS) and normal (NORM).

Results and Discussion

After first data reduction with LAMP software, the longitudinal component gave no diffraction signal in multiple locations, so that no clear strain tendency could be assessed and hence no stress calculation is possible.

a) b)

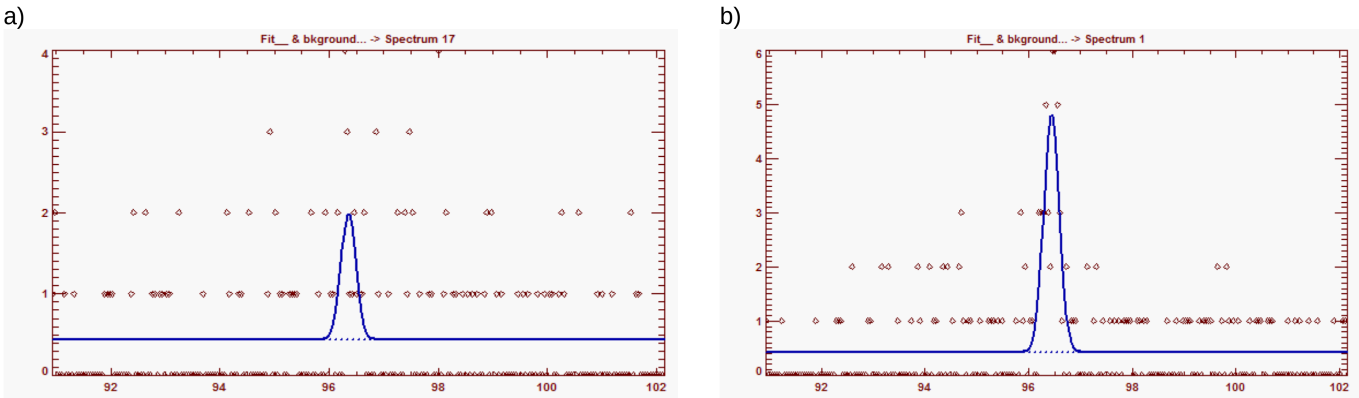

Figure 5. Problematic of LAMP data reduction for (a) as welded and (b) post weld heat treated in longitudinal component. (Please find the data in the attachment A.)

With the aim of making a first estimation of the tendency of stresses, we deleted the most critical points (errors in 2Theta peak position>0.03) and calculated those as disclosed in Fig.6. However only transversal and normal components would be publishable. Furthermore, the chosen reference from the base material should be improved since microstructural changes across the weld have a strong influence already in the strain calculations.

a) b)

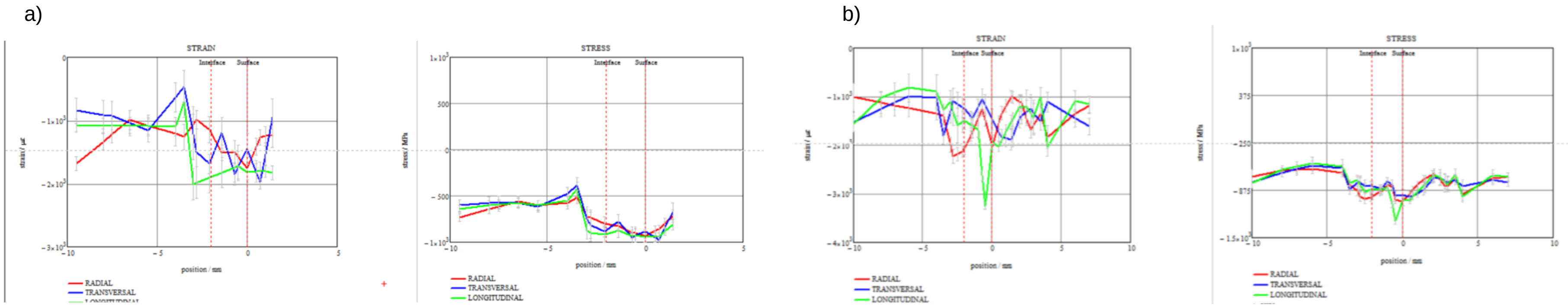

Figure 6. Strain and stress components after point reduction (a) as welded and (b) heat treated.

Conclusion and next actions

In the present test there was a conflict between material properties (large grains) and instrumental gauge volume, especially for the longitudinal component and certainly texture. Before new stress scans can be performed, texture needs to be evaluated at different locations: parent material, heat affected zone and weld seam centre. This could be done destructively on the present samples using synchrotron X-rays.

For this samples we could not have enlarged the gauge volume, since spatial resolution resolution decreases (HAZ < 1 mm, fusion zone 7.5-2mm), because of the specific use of the alloy, therefore we would like to have a complete strain tensor measurement of another material e.g. aluminium.

Nevertheless the data obtained for transverse and normal strains will help towards in-house process simulation tools.

Attachments

A- Problematic of LAMP data reduction for (a) as welded and (b) post weld heat treated in longitudinal component.

a) as welded;

pirlinPIRL	HT-'50	line	18	LONG	Tx	Fit_function:Gauss				
salsa	Date	########	Time	13:28:09	Run	26863	**26861:26863**			
w2=str_in…	...	w1=RDOP	..SALSA							
Mean	CHI	square	=	0.57						
Call:	par=str_fit	file	titl	Win=2	Bkgd="flat	Fit=f	Res_Dfit=(	Sigma=s	ConvFunc	Out_SubF=o)

Spectra	pseudo_V	e	height	e	center	e	fWmH	e	backgrour	e	(+a1.x	+a2.x^2)	a2	e	fit_area	e	raw_int	Xtransl.	Ytransl.	Ztransl.	Omega	2_theta	Xrotation	Yrotation	Zrotation	Monitor	Time
1	0	0	2.433737	0.375957	96.4912	0.02912	0.362621	0.069465	0.479288	0.050464	0	0	0	0	0.939417	0.23118	1.123719	-10	0	-18	-46.33	96.202	0	0	0	144	300000
2	0	0	2.910481	0.288799	96.36355	0.033591	0.693223	0.081156	0.481784	0.054225	0	0	0	0	2.147682	0.329593	2.141723	-8	0	-18	-38.06	96.202	0	0	0	172	300000
3	0	0	5.069827	0.480124	96.35152	0.014854	0.314986	0.035355	0.505785	0.058851	0	0	0	0	1.699874	0.24964	1.735104	-6	0	-18	-43.07	96.202	0	0	0	168	300000
4	0	0	3.687718	0.302371	96.35563	0.022472	0.562576	0.053994	0.581884	0.050398	0	0	0	0	2.208367	0.278766	2.07519	-4	0	-18	-44.78	96.202	0	0	0	199	300000
1	0	0	2.729235	0.323698	96.29369	0.028174	0.491047	0.067495	0.533884	0.0499	0	0	0	0	1.42658	0.258992	1.436938	-3.5	0	-18	-37.12	96.202	0	0	0	169	300000
2	0	0	4.550075	0.353734	96.3465	0.016726	0.44022	0.039995	0.451909	0.051567	0	0	0	0	2.132165	0.254952	2.212025	-3	0	-18	-45.32	96.202	0	0	0	164	300000
3	0	0	4.0492	0.462396	96.37234	0.010019	0.178239	0.023727	0.424192	0.0419	0	0	0	0	0.768252	0.134741	0.763546	-2.5	0	-18	-41.08	96.202	0	0	0	126	300000
4	0	0	1.832245	0.236168	96.32967	0.043071	0.772357	0.104129	0.331154	0.044913	0	0	0	0	1.506378	0.280973	1.398828	-2	0	-18	-38.72	96.202	0	0	0	119	300000
5	0	0	3.864541	0.454629	96.433	0.011987	0.206385	0.028415	0.460016	0.044496	0	0	0	0	0.849001	0.153749	1.058205	-1.5	0	-18	-46.61	96.202	0	0	0	137	300000
6	0	0	4.277907	0.497369	96.43095	0.009807	0.170679	0.023219	0.388244	0.044133	0	0	0	0	0.777219	0.139085	1.000159	-1	0	-18	-39.7	96.202	0	0	0	117	300000
7	0	0	2.862084	0.357496	96.43026	0.01995	0.316058	0.047491	0.40304	0.044127	0	0	0	0	0.962899	0.188148	1.257888	-0.5	0	-18	-38.6	96.202	0	0	0	125	300000
8	0	0	4.075672	0.355388	96.43247	0.018214	0.432524	0.043534	0.376892	0.05108	0	0	0	0	1.876471	0.249888	1.936859	0	0	-18	-46.83	96.202	0	0	0	139	300000
9	0	0	2.705507	0.306864	96.41968	0.02867	0.515112	0.068763	0.37261	0.048835	0	0	0	0	1.483482	0.259861	1.5223	0.5	0	-18	-38.63	96.202	0	0	0	129	300000
10	0	0	1.148095	0.210901	96.33601	0.089524	1.031739	0.219418	0.419634	0.049391	0	0	0	0	1.260898	0.354338	1.021349	1	0	-18	-40.68	96.202	0	0	0	136	300000
11	0	0	1.405009	0.403631	97.48242	0.024836	0.141086	0.056378	0.387322	0.035904	0	0	0	0	0.211007	0.103846	0.34264	1.5	0	-18	-46.35	96.202	0	0	0	104	300000
12	0	0	2.760193	0.541289	93.81112	0.007116	0.045521	0.012588	0.398109	0.029098	0	0	0	0	0.133747	0.045341	0.225518	2	0	-18	-37.36	96.202	0	0	0	105	300000
13	0	0	1.56262	0.384932	96.35706	0.041005	0.323125	0.097655	0.440679	0.048379	0	0	0	0	0.537472	0.209559	0.500876	2.5	0	-18	-44.69	96.202	0	0	0	125	300000
14	0	0	2.287406	0.335574	96.45668	0.030998	0.41467	0.07408	0.363729	0.048055	0	0	0	0	1.009666	0.2334	1.213996	3	0	-18	-41.82	96.202	0	0	0	116	300000
15	0	0	3.143596	0.307709	96.29012	0.029362	0.614502	0.070703	0.517209	0.05393	0	0	0	0	2.05628	0.310624	2.22304	3.5	0	-18	-38.9	96.202	0	0	0	179	300000
1	0	0	5.300928	0.346699	96.33877	0.017002	0.535732	0.040805	0.509782	0.056149	0	0	0	0	3.022957	0.303488	3.090041	4	0	-18	-46.99	96.202	0	0	0	199	300000
2	0	0	2.46998	0.303232	96.26986	0.037688	0.626602	0.090804	0.576828	0.053819	0	0	0	0	1.64747	0.312898	1.709919	6	0	-18	-38.41	96.202	0	0	0	185	300000
3	0	0	5.003948	0.456108	96.33762	0.012405	0.276266	0.02948	0.518191	0.051965	0	0	0	0	1.471542	0.206517	1.657802	8	0	-18	-42.49	96.202	0	0	0	166	300000
4	0	0	2.587061	0.322667	96.33266	0.040755	0.686028	0.098384	0.461676	0.05962	0	0	0	0	1.889212	0.359063	1.993365	10	0	-18	-46.08	96.202	0	0	0	161	300000

b) with post weld heat treatment

pirlinPIRL	HT-'50	line	54	LONG	Tx	Fit_function:Gauss				
salsa	Date	########	Time	15:24:44	Run	26866	**26864:26866**			
w2=str_in…	...	w1=RDOP	..SALSA							
Mean	CHI	square	=	0.65						
Call:	par=str_fit	file	titl	Win=2	Bkgd="flat	Fit=f	Res_Dfit=(	Sigma=s	ConvFunc	Out_SubF=o)

Spectra	pseudo_V	e	height	e	center	e	fWmH	e	backgrour	e	(+a1.x	+a2.x^2)	a2	e	fit_area	e	raw_int	Xtransl.	Ytransl.	Ztransl.	Omega	2_theta	Xrotation	Yrotation	Zrotation	Monitor	Time
1	0	0	4.407	0.349412	96.44161	0.013758	0.352949	0.03279	0.427682	0.045307	0	0	0	0	1.65572	0.202221	1.400295	-10	0	-54	-46.93	96.202	0	0	0	147	300000
2	0	0	4.59487	0.419052	96.35683	0.013843	0.29808	0.032933	0.488099	0.050281	0	0	0	0	1.457935	0.208866	1.352714	-8	0	-54	-39	96.202	0	0	0	158	300000
3	0	0	2.800897	0.472341	96.33961	0.026847	0.299835	0.063895	0.596534	0.057695	0	0	0	0	0.893946	0.242935	0.68967	-6	0	-54	-41.69	96.202	0	0	0	172	300000
4	0	0	3.356976	0.412172	96.45875	0.023782	0.401424	0.056772	0.560548	0.056819	0	0	0	0	1.434446	0.268653	1.410553	-4	0	-54	-46.06	96.202	0	0	0	176	300000
1	0	0	3.407199	0.312941	96.32853	0.0238	0.533259	0.057116	0.457722	0.05058	0	0	0	0	1.93405	0.272886	1.877313	-3.5	0	-54	-37.59	96.202	0	0	0	161	300000
2	0	0	2.212926	0.251656	96.3863	0.040465	0.732149	0.097918	0.374699	0.048672	0	0	0	0	1.724639	0.302767	1.413383	-3	0	-54	-44.11	96.202	0	0	0	135	300000
3	0	0	2.123028	0.232186	96.35347	0.042937	0.784525	0.104213	0.444604	0.047285	0	0	0	0	1.772943	0.305059	1.823239	-2.5	0	-54	-42.5	96.202	0	0	0	154	300000
4	0	0	2.756352	0.331244	96.35619	0.030513	0.538926	0.073205	0.481112	0.053165	0	0	0	0	1.581233	0.28678	1.606667	-2	0	-54	-38.03	96.202	0	0	0	159	300000
5	0	0	4.874985	0.38556	96.38789	0.016076	0.414117	0.038403	0.524646	0.054453	0	0	0	0	2.148962	0.261917	1.751055	-1.5	0	-54	-46.84	96.202	0	0	0	183	300000
6	0	0	5.099708	0.419035	96.41971	0.01673	0.414568	0.039966	0.503948	0.059228	0	0	0	0	2.250469	0.285068	2.332048	-1	0	-54	-37.96	96.202	0	0	0	180	300000
7	0	0	5.370367	0.507311	96.45945	0.009723	0.210382	0.023052	0.530283	0.049996	0	0	0	0	1.202663	0.173991	1.347711	-0.5	0	-54	-43.77	96.202	0	0	0	162	300000
8	0	0	3.732721	0.303976	96.44805	0.018663	0.468198	0.044676	0.518951	0.045853	0	0	0	0	1.860317	0.233371	1.735468	0	0	-54	-41.24	96.202	0	0	0	174	300000
9	0	0	7.808941	0.790488	96.61659	0.005028	0.099391	0.012032	0.590943	0.053206	0	0	0	0	0.826171	0.130373	0.74446	0.5	0	-54	-41.91	96.202	0	0	0	170	300000
10	0	0	5.063116	0.395391	96.41679	0.017324	0.445644	0.041442	0.607722	0.058403	0	0	0	0	2.401807	0.29166	2.496663	1	0	-54	-45.51	96.202	0	0	0	210	300000
11	0	0	5.300864	0.363625	96.40235	0.014326	0.426689	0.034238	0.490037	0.052141	0	0	0	0	2.407633	0.254167	2.253652	1.5	0	-54	-37.14	96.202	0	0	0	180	300000
12	0	0	4.159962	0.363064	96.39049	0.022168	0.512411	0.053169	0.471038	0.057809	0	0	0	0	2.269027	0.30765	2.231557	2	0	-54	-46.35	96.202	0	0	0	172	300000
13	0	0	2.290313	0.322903	96.4041	0.045792	0.54028	0.109785	0.503309	0.057138	0	0	0	0	1.317183	0.325767	1.290797	2.5	0	-54	-38.19	96.202	0	0	0	159	300000
14	0	0	2.892375	0.348491	96.34241	0.028699	0.491365	0.068755	0.541881	0.053785	0	0	0	0	1.512833	0.279347	1.646326	3	0	-54	-46.29	96.202	0	0	0	173	300000
15	0	0	5.912024	0.382535	96.36161	0.01111	0.346336	0.026474	0.451615	0.049249	0	0	0	0	2.179543	0.218277	2.034793	3.5	0	-54	-37.37	96.205	0	0	0	165	300000
1	0	0	2.219092	0.326913	96.31458	0.043076	0.610568	0.103674	0.505149	0.056663	0	0	0	0	1.442252	0.324216	1.338854	4	0	-54	-46.06	96.205	0	0	0	162	300000
2	0	0	2.2151	0.312592	96.30441	0.035193	0.500231	0.084374	0.551838	0.049232	0	0	0	0	1.179495	0.259393	1.118852	6	0	-54	-37.51	96.205	0	0	0	168	300000
3	0	0	4.95075	0.34315	96.33111	0.013789	0.408052	0.032929	0.465919	0.047959	0	0	0	0	2.150395	0.228757	2.116263	8	0	-54	-46.74	96.205	0	0	0	168	300000
4	0	0	4.67274	0.338134	96.4001	0.019277	0.546658	0.046287	0.353097	0.055469	0	0	0	0	2.719066	0.302854	2.383299	10	0	-54	-37.41	96.205	0	0	0	152	300000