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The Effects of Shot and Grit Blasting Process Parameters on Steel Pipes Coating Adhesion

Saeed Khorasanizadeh

***Abstract*—**Adhesion strength of exterior or interior coating of steel pipes is too important. Increasing of coating adhesion on surfaces can increase the life time of coating, safety factor of transmitting line pipe and decreasing the rate of corrosion and costs. Preparation of steel pipe surfaces before doing the coating process is done by shot and grit blasting. This is a mechanical way to do it. Some effective parameters on that process, are particle size of abrasives, distance to surface, rate of abrasive flow, abrasive physical properties, shapes, selection of abrasive, kind of machine and its power, standard of surface cleanness degree, roughness, time of blasting and weather humidity. This search intended to find some better conditions which improve the surface preparation, adhesion strength and corrosion resistance of coating. So, this paper has studied the effect of varying abrasive flow rate, changing the abrasive particle size, time of surface blasting on steel surface roughness and over blasting on it by using the centrifugal blasting machine. After preparation of numbers of steel samples (according to API 5L X52) and applying epoxy powder coating on them, to compare strength adhesion of coating by Pull-Off test. The results have shown that, increasing the abrasive particles size and flow rate, can increase the steel surface roughness and coating adhesion strength but increasing the blasting time can do surface over blasting and increasing surface temperature and hardness too, change, decreasing steel surface roughness and coating adhesion strength.

***Keywords*—**surface preparation, abrasive particles, adhesion strength

I. Introduction

THE necessary specified of coating systems is adhesion. The industrial coatings have not enough strength in their structure but they are like the body skin and they can protect bases or substrates against corrosion. When the tension on the coating is more than adhesion strength of coating on substrate the peeling of coating is produced. Kinds of adhesion: The bond between substrate & coating consists of: chemical, polar & mechanical adhesion. Adhering of epoxy on steel surface is a chemical adhesion & the polar adhering is a usual organic adhesion but their adhesion between substrate and them is weak. The coating adhesion depends on the surface roughness too much. It is called the mechanical adhesion. When the surface of substrate is roughed, the active points on the surface are increased, so polar and chemical bonds are increased. The shape of abrasive particles can effect on surface roughness. If abrasive particles have more spherical shape, the surface has more valleys by less depth. If abrasive particles have more angular shape, the surface of substrate is rougher by deep valleys but it may some fine particles penetrate in substrate. The abrasive particle size can effect on rate of cleanness velocity and number of picks & valleys. In fact, when the abrasive particles are bigger, the picks and valley are increased but cleanness velocity is decreased [1]. Surface preparation can be performed by different ways but the grit blasting is one the most effectiveness way to remove weakness layers of substrate surface and this way can modified the chemical bonds between coating and substrate. Fig. 1 is shown a roughed surface in two and three dimensions after grit blasting [2].

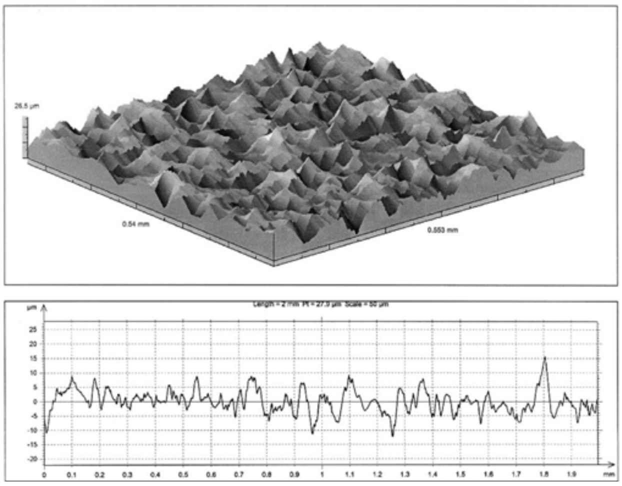

Fig. 1 Roughed surface in two and three dimensions after grit blasting [2]

One of the most important targets of interior & interior coating of transmitting steel pipes surfaces is prevention of corrosion. There are kinds of coating which to apply as exterior coating for steel pipes such as wax & vinyl, coal tar, yellow jacket, polyethylene tape, 3layer, tape & High Performance Composite Coating (HPCC) [3] [4]. Surface roughness, parameters and criterions: It must not to provide roughed surface by applying high tension on surface. The surface roughness must be provided regarding to the coating material and thickness of coating. The optimum roughness and profile can be provided by changing the parameters which are density, profile of velocity, size and hardness of abrasive particles. As usual criterions of roughness are R_a, $R_{max,}$ R_t and R_z. see the fig. 2 [5].

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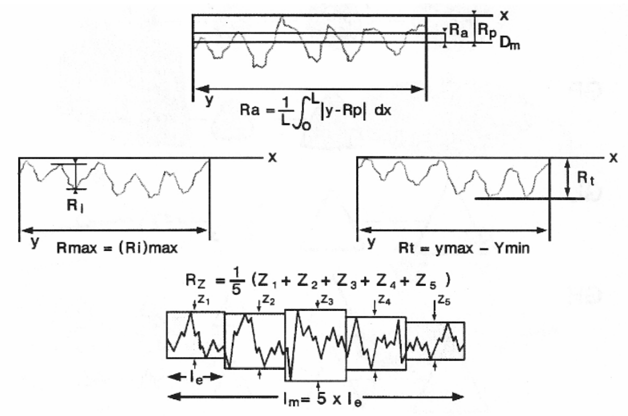

Fig. 2 Criterions of roughness are R_a, $R_{max,}$ R_t and R_z [5]

pull-off test is important to measure the coating adhesion strength because it is shown that how much the coating has strength adhesion on substrate and how much the preparation of substrate has been done well [6].

II. Methods and Materials

This research is an applicable object which has done by experimental work, soft wares package and statistics analysis. First step: 20 steel specimens in four groups (there are 5 specimens in each group) were blasted by four different abrasive flow rates. After that they were coated by epoxy powder according the epoxy powder manufacturer instruction. Second step: 10 steel specimens in two groups (there are 5 specimens in each group) were blasted by two different abrasive particle size, after that they were coated by epoxy powder according the epoxy powder manufacturer instruction. Third step: the time of blasting was varied for 11 specimens. The surface temperature, roughness and hardness of them were measured. The blasting time was continued till the surface was over blasted. All specimens were coated in the end of each step by epoxy powder according the epoxy powder manufacturer instruction. Pull-Off test was done for all specimens in each step and the results were recorded and compared by each other.

A. Steel specimens specifications

All specimens were of steel X52 according API 5L standard by L=10 cm, W=8 cm, Th. =0.635 cm. Chemical analysis was done according to ASTM A751 by Spectro Model Ms (made in Germany) and recorded in table 1. Grade of rust of specimens surfaces were "C" according to ISO 8501. See Fig. 3. Yield and tensile strength were 449.938 and 558.199 Mpa respectively.

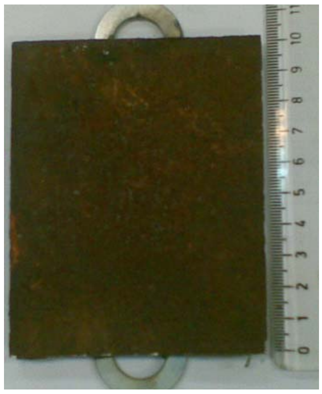

Fig. 3 Grade of Rust of specimen surface "C" according to ISO 8501

TABLE I
CHEMICAL ANALYSIS OF STEEL SPECIMEN

FE_10A LOW-ALLOY-STEEL 01/09/10 11:06
SAMPLE ID EN.Khorasani Zade

	C	Si	Mn	P	S	Cr	Mo	Ni	Al	B
1	0.126	0.215	1.35	0.0114	.00278	0.0151	<.00100	0.0271	0.0388	<.00020
2	0.120	0.215	1.34	0.0113	.00295	0.0148	<.00100	0.0268	0.0393	<.00020
3	0.142	0.216	1.34	0.0121	.00357	0.0150	<.00100	0.0270	0.0405	<.00020

	Co	Cu	Nb	Pb	Sn	Ti	V	W	Zr	Sb
1	<.00500	0.0366	0.0156	<.00100	.00153	0.0280	<.00100	0.0217	<.00100	<.00500
2	<.00500	0.0406	0.0149	<.00100	.00121	0.0277	<.00100	0.0228	<.00100	<.00500
3	<.00500	0.0425	0.0163	<.00100	.00115	0.0279	.00120	0.0216	<.00100	<.00500

	Ta	Fe	C-eq	Pcm
1	<.00500	98.09	?0	?0
2	<.00500	98.10	?0	?0
3	<.00500	98.07	?0	?0

FE_10A LOW-ALLOY-STEEL 01/09/10 11:06
SAMPLE ID EN.Khorasani Zade
Average of 3 sparks

	C	Si	Mn	P	S	Cr	Mo	Ni	Al	B
Min										
X	0.129	0.216	1.35	0.0116	.00310	0.0150	<.00100	0.0270	0.0395	<.00020
Max										

	Co	Cu	Nb	Pb	Sn	Ti	V	W	Zr	Sb
Min										
X	<.00500	0.0399	0.0156	<.00100	.00130	0.0279	<.00107	0.0220	<.00100	<.00500
Max										

	Ta	Fe	C-eq	Pcm
Min				
X	<.00500	98.09	0.361	0.208
Max				

B. Coating specifications

KCC EX4413-L300 B/GREEN HD epoxy powder (made in South Korea) for steel specimens coating process according the manufacturer instruction was used. The epoxy coating was applied by Optiflex C device (made by Gema Swiss). The thickness of epoxy coating 150±15 micron which was measured by Elktro Physic Mini Test 4100 (made in Germany). The operational conditions for step 1, 2 and 3 for applying epoxy coating were recorded in table 2. The measuring was done by Testo 615 (made in Germany).

TABLE II
OPERATIONAL CONDITIONS FOR APPLYING EPOXY COATING

Step	Environmental temperature (°C)	Relevant humidity %	Dew point (°C)
1	23	47.6	11.6
2	25	49	12.3
3	22	48.1	12.1

C. Centrifugal shot blasting machine specifications

A 55 kw centrifugal shot blasting machine was used by wheel diameter= 500 mm, No. of blades= 8, radius speed of wheel= 2250 rpm, speed of abrasive particles from outgoing of turbine wheel= 80 m/sec, maximum flow rate= 12 kg/sec, angle of abrasive blasting= 85 degree, blasting distance= 65 cm. The unload current of turbine wheel driver motor was 34.5 (A) was measured. To set up the current of turbine wheel driver motor it was adjusted by the variation of abrasive flow rate feeding valve.

D.Shot and Grit specifications

Mixture of tempered martensite shot (S390) and grit (GL18) abrasives were used (30% and 70% mass respectively). The hardness of shot particles was 37-42 HRC and hardness of grit particles was 43-48 HRC. The density of them was 7.5 gr/cm^3, and the chemical analysis of them is recorded in table 3. The used abrasives were made by Faravardehay-e- Fooladi-e- Gorgan-Iran.

TABLE III
CHEMICAL ANALYSIS OF ABRASIVE

Carbon	0.85-1.20%
Manganese	0.6-1.20%
Silicon	40% min.
Sulfur	0.05% max.
Phophorus	0.05% max.

E. Roughness, hardness, adhesion strength and surface temperature measurements

All of the surfaces roughnesses were measured by Hommel Tester T1000 E-320. All of adhesion strength was measured by Elcometer 108 device according to ISO 4624 standard. The 3M Scotch-Weld M2000 was used for conjunction between Dolly and surface epoxy coating [7]. The Impact Tastotherm D1200 was used for surface temperature measurements.

F. Abrasive particles size analysis

The abrasive particle sizes analysis was done according to ASTM E11:81. The mass of the abrasive sample was 500 gr. and there were four samples. The masses were measured by Mettler AE160. The results of the sieve analysis are in table 4 and fig. 4. The sample 1 was selected after 16 hours when the sample 2 was used for production in coating plant. Sample 3 and 4 were new in stock.

III. THE RESULTS

A. Table 5

The results of three steps of experiments are in table 5. Item 1 up to 20 are related to step 1, item 21 up to 30 are related to step 2 and item 31 up to 41 are related to step 3.

B. Figures by respect to the results of table 5

Fig. 6, 7, 9, 10 and 14 show the adhesion strength according to R_t. Fig. 8 and 11 show the adhesion strength according to turbine wheel driver motor current. Fig. 12 shows the surface hardness according the time of blast. Fig. 13 shows the R_t according the time of blast and Fig. 15 shows the coated specimen after Pull-Off test.

TABLE IV
RESULTS OF THE SIEVE ANALYSIS

Sample		Sieve analysis (Mesh (μm))								
		1700	1180	800	600	425	300	212	150	125
1	Mass (gr)	0	47	128	137	111	52	16	2	0
	%	0	9.4	25.6	27.4	22.6	10.4	3.2	0.4	0
2	Mass (gr)	0	70	113	218	74	20	5	0	0
	%	0	14	22.6	43.6	14.8	4	1	0	0
3	Mass (gr)	0	312	180	8	0	0	0	0	0
	%	0	62.4	36	1.6	0	0	0	0	0
4	Mass (gr)	0	400	90	7	3	0	0	0	0
	%	0	80	16	1.4	0.6	0	0	0	0

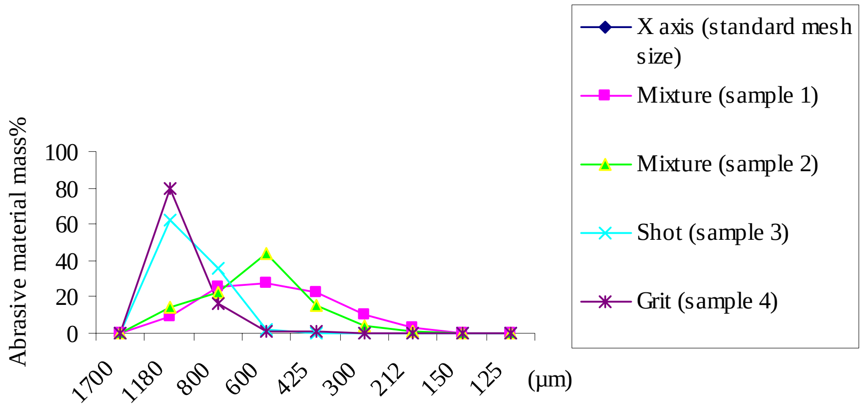

Fig. 4 Results of abrasive particle sizes (standard sieve analysis)

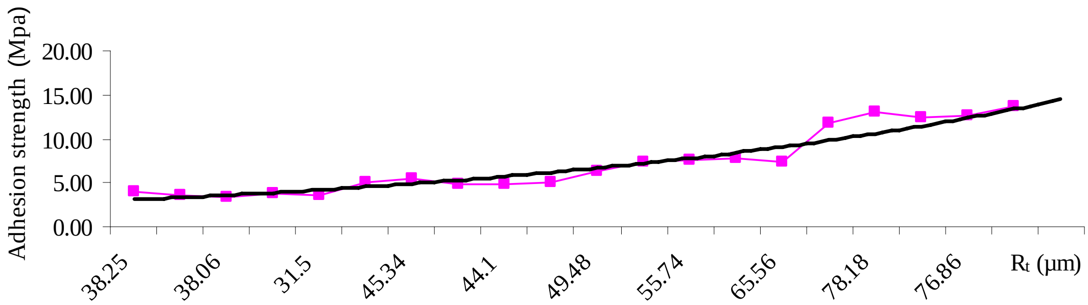

Fig. 6 Results of Adhesion strength for step 1

Fig. 7 Results of average of adhesion strength for step 1

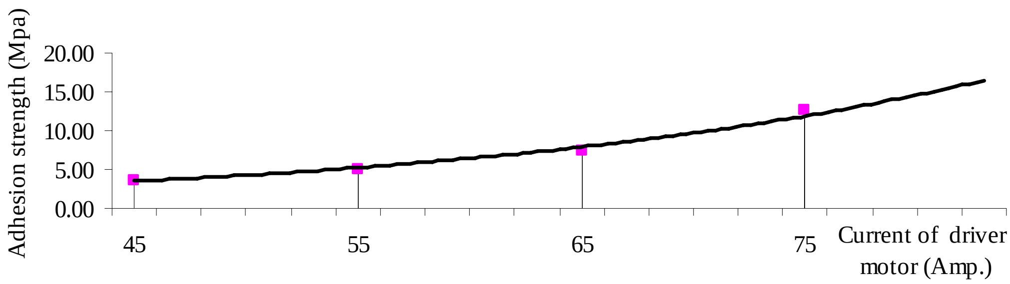

Fig. 8 Results of Adhesion strength for step 1 by different wheel driver motor current

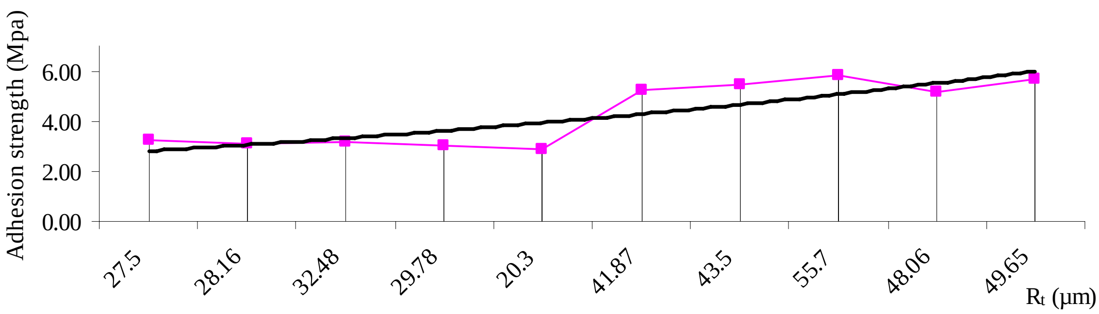

Fig.9 Results of Adhesion strength for step 2

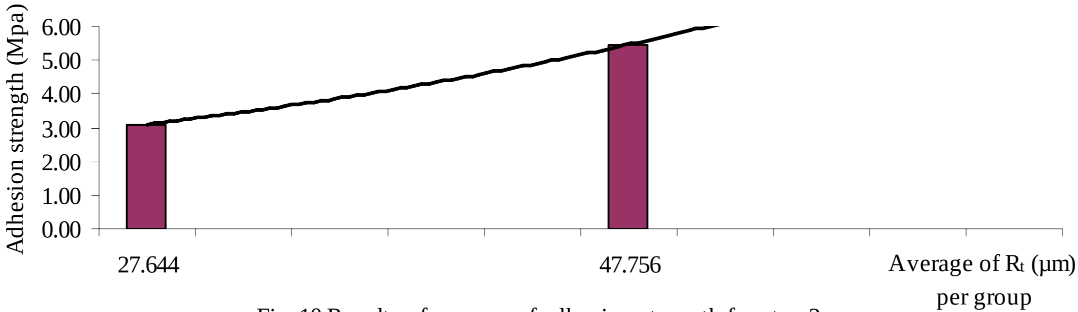

Fig. 10 Results of average of adhesion strength for step 2

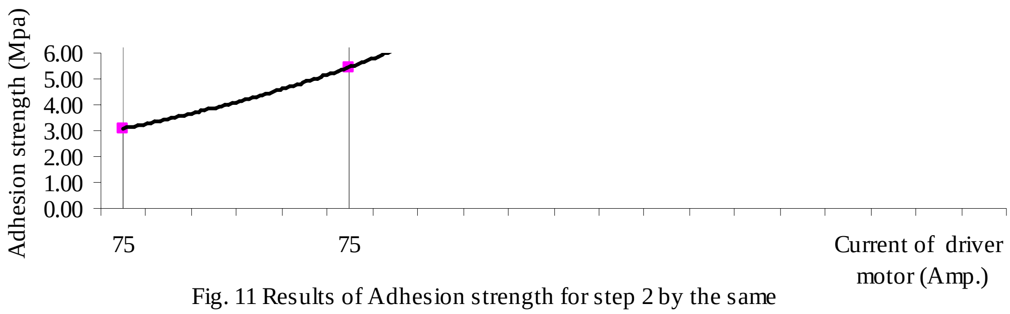

Fig. 11 Results of Adhesion strength for step 2 by the same wheel driver motor current

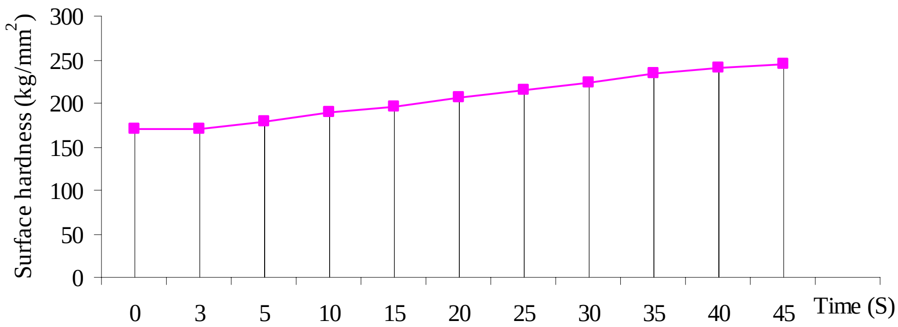

Fig. 12 Results of surface hardness for different blast time for step 3

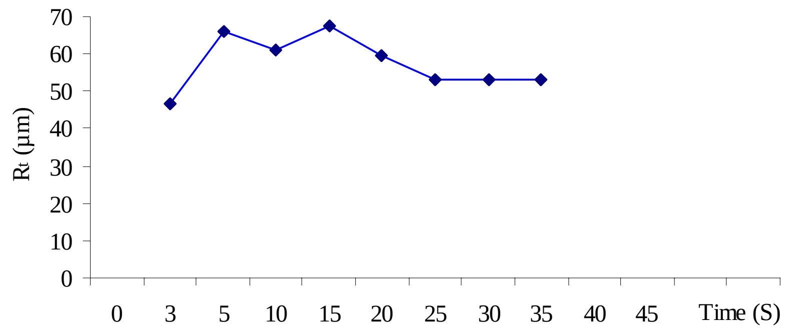

Fig. 13 Results of surface roughness for different blast time for step 3

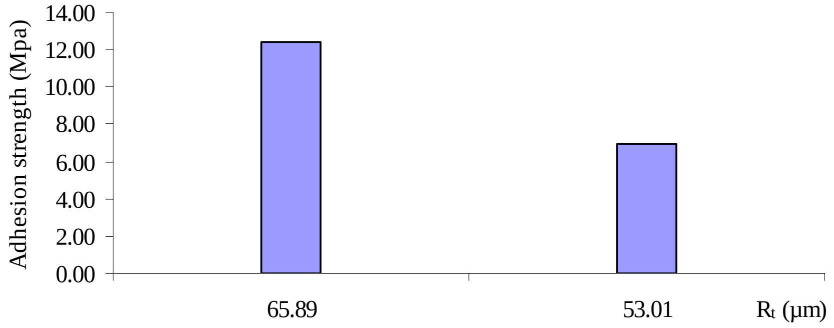

Fig.14 Results of adhesion strength for step 3

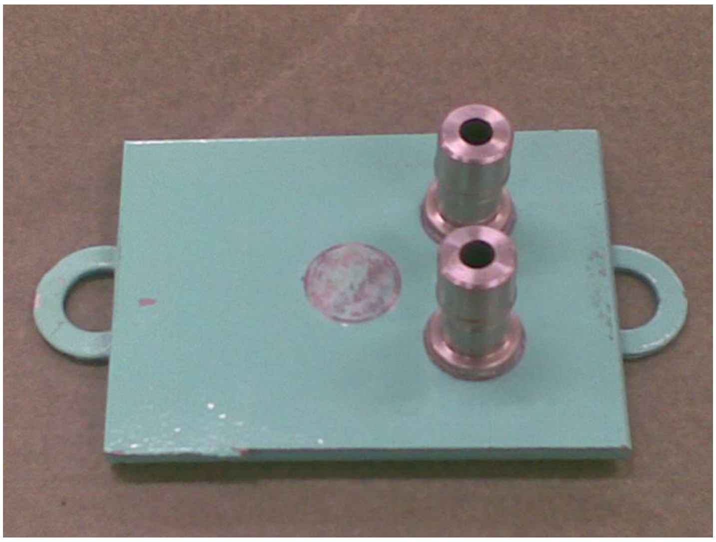

Fig. 15 Coating after Pull- Off test by dolly 20 mm diameter

TABLE V
RESULTS OF THREE STEPS OF EXPERIMENTS

Step	Item	Group	Turbine wheel driver motor current (Amp.)	Blast time(S)	Surface temp. (ºC)	Average of 5 points surface hardness (kg/mm^2)	Average of 10 points for R_t (µm)	Average R_t(µm) per Group	Average of adhesion strength for 3 points (Mpa)	Average of adhesion strength per group (Mpa)
	1						38.25		4.00	
	2						33.10		3.66	
	3	1	45				38.06	34.275	3.36	3.66
	4						30.48		3.78	
	5						31.50		3.52	
	6						45.67		5.03	
	7						45.34		5.50	
	8	2	55				48.36	46.582	4.84	5.07
	9						44.10		4.90	
	10						49.44		5.06	
1	11						49.48		6.27	
	12						59.63		7.46	
	13	3	65				55.74	59.246	7.56	7.27
	14						65.82		7.80	
	15						65.56		7.27	
	16			5	-	-	66.13		11.73	
	17						78.18		13.15	
	18	4	75				72.24	75.768	12.42	12.70
	19						76.86		12.55	
	20						85.43		13.64	
	21						27.50		3.24	
	22						28.16		3.11	
	23	5	75				32.48	27.644	3.19	3.09
	24						29.78		3.05	
	25						20.30		2.84	
2	26						41.87		5.22	
	27						43.50		5.43	
	28	6	75				55.70	47.756	5.80	5.46
	29						48.06		5.18	
	30						49.65		5.68	
	31		0	0	18	169.2	-		-	
	32			3	18	170	46.475		-	
	33			5	20	177.66	65.892		12.42	
	34			10	21.8	189.83	61.154		-	
	35			15	23.5	195.78	67.360		-	
3	36	7	75	20	25.9	206	59.670	-	-	-
	37			25	28.1	214	53.010		6.93	
	38			30	31.3	222.7	53.018		-	
	39			35	34.7	233	53.010		-	
	40			40	37	240.5	53.011		-	
	41			45	38.1	244.1	53.011		-	

IV. DISCUSSION

It is important to know that increasing the turbine wheel driver motor current of centrifugal blasting unit means increasing the rate of abrasive flow and it can increase the surface coverage and R_t. See fig. 6, 7 and 8. Because of difference of the surface coverage in step 1 could prepare the difference between results in adhesion strength. See fig. 5. By respect to fig. 9, 10, 11 can be known the difference of the two different abrasive particle sizes can effect on R_t. The areas under curves of all abrasive samples calculated. This was done by drawing the curves by Auto Cad software and their areas under them were calculated. The results were recorded in table 6.

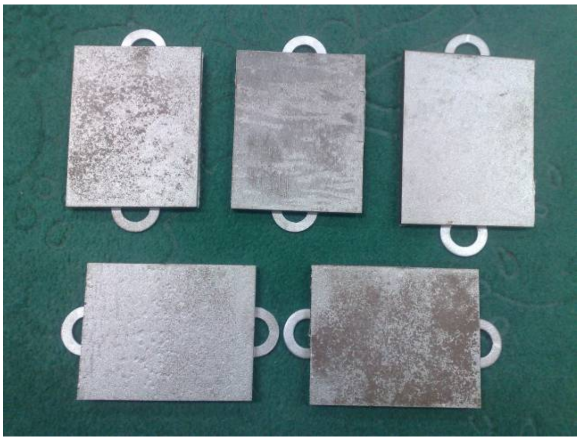

Fig. 5 Incomplete coverage of steel surfaces specimens

TABLE VI
RESULTS OF AREAS UNDER CURVES

Abrasive particles sample	Area under curve (square unit)	Average of area
Grit (sample 4)	20800	20105
Shot (sample 3)	19410	
Mixture (sample 2)	11876	-
Mixture (sample 1)	10750	-

As it is shown the area of sample 1 is around 53% and the area of sample 2 is around 60% of average of sample 3 and 4 curve area. To pay attention to kinetic equation (1),

$$E = \tfrac{1}{2} m v^2 \quad (1)$$

m is the mass and v is the speed of abrasive particle. Because of the speed of two different abrasive particle sizes are the same and the fine abrasive particle has less mass, so the fine particle has less energy. For this reason the fine particles can do roughening the substrate surface less than coarse particles. Less roughed surface can have less mechanical adhesion to coating. If to pay attention to results for group 7 in table 5, it is known that increasing the blast time can increase the surface temperature and hardness. If the steel surface temperature is increases it is possible to remain some abrasive particles on surface and they can not come back.

So this matter can decrease the cleanness of the steel surface and decrease the chemical and mechanical adhesion strength. Increasing the blast time (over blasting) can decrease the surface roughness and mechanical adhesion of coating. The results of Pull-Off test have been shown in table 5.

V. CONCLUSION

Because of using centrifugal blasting machine for preparation of steel surface pipe in fluids transmitting pipe lines, it is too important to do right parameters related to blasting machine and operations. Further more the Pull-Off test can show the operators which how the surface preparation has been done right. Increasing the roughness of the steel surface can increase the adhesion strength of coating because the roughed surface has more active surface to have a touch surface with coating. Variation of the abrasive flow rate can effect on steel surface coverage and roughness. Increasing the abrasive flow rate can increase the steel surface coverage and roughness and so the coating can have more adhesion strength. Using of the coarse abrasive particle sizes can provide the more roughed surface in the same condition in the coating of steel pipes production. It is so important that if there is 100% coverage can not be reasonable to have very well adhesion strength for coating. It means that if the more adhesion strength is needed, the roughed surface must be provided. Calculation of the effectiveness useful power for centrifugal blasting machine can be done by calculation the area under the sieve analysis curve of the abrasive particles and compare with the reference curves. The blast time is limited. It means that it is not right to increase the blast time more and more for to take good steel surface. Because this matter produces the over blasted surface and decrease the surface roughness and adhesion strength of coating. Further more increase the surface temperature and surface hardness.

VI. RECOMMENDATIONS

Increasing the steel surface hardness after over blasting can increase the surface wet ability property [8], so it can be an object to study about this effect on corrosion rate and corrosion tension after applying the coating.

The coaters of transmitting steel pipe lines can provide a soft ware program to process some data which they can collect them from abrasive particles sieve analysis for optimizing usage of centrifugal blasting machine in steel pipe surface preparation and save the energy more and cost.

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