Drying of steel pipes at a hot-dip galvanizing plant by induction heating

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In the dry galvanizing process, pipes are subjected to chemical treatment and then dried in a continuous drying furnace which is followed by the galvanizing kettle. However, drying furnaces used in a dry galvanizing process, lead to some problems. The impossibility of achieving a uniform temperature distribution along the pipe in conventional drying furnaces and the negative impacts thereof on the product quality make it inevitable to seek new approaches towards pipe drying. In this study, instead of in a drying furnace, the fluxed pipes were dried at the line by means of induction heating. By using an induction heating system, the pipes were heated up much more uniformly than by the conventional drying method. It is observed that the temperature change along the pipe surface varied by ±5 °C while it was 15-20 °C in the conventional system. In addition, the problem of black spots, seen very frequently at galvanizing plants, was eliminated completely.

Article Information

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Hot dip galvanizing is the process of forming a protective coating against corrosion on metal surfaces by immersing it in a molten zinc bath [1, 2]. The resistance of zinc coating against mechanical stresses and damages is largely due to the metallurgical bond between the steel surface and the coating. Some of the most important benefits of galvanizing is the possibility of physically coating any areas at minimum thickness conforming to technical standards and high corrosion resistance in various environments [3, 4].

Galvanization is a diffusion controlled process. When the material is immersed into the molten zinc bath, first its temperature reaches the temperature of the molten zinc and then, by the diffusion-reaction, it becomes composed of a range of Fe-Zn intermetallic phases getting richer in Fe from the coating surface toward the base material and having various thicknesses and properties [5, 6]. Zinc coating, in the outermost surface, is composed of, eta (η-0.03 % Fe) being called pure zinc and as intermetallic Fe-Zn compounds, zeta (ξ-6-7 % Fe), delta (δ- 8-13 % Fe) and gamma (Γ-18-31 % Fe), the Fe contents of which increase from the specimen's surface toward the inner layers and their mechanical properties are different from each other due to their structural heterogeneity [7, 8]. Zn/Fe alloy layers are rather hard and brittle and their mechanical formability (bending, flexing, etc.) is quite limited. On the other hand, the pure zinc layer is softer and more resistant to such kind of mechanical stresses [6]. Effective corrosion resistance performance of hot dip galvanized coatings depends on the composition of intermetallic layers and layer-wise morphology and topography. The protection performance is proportional to thickness of the coating layer [9]. The presence, thickness and distribution of Zn-Fe alloy layers determine the characteristics of the product and depend on the chemical composition of the zinc bath [7, 10-12], the chemical composition of steel [6], the temperature of zinc bath and sample [13, 14], immersion time [7, 10, 14], cooling rate [15], the surface roughness of specimen [16], the withdrawal velocity and angle from the bath [17, 18], and whether or not any procedure has been applied before [19]. It is indicated that bath temperature and dipping time, as a result of line speed, are specific operating parameters that can be optimized to control efficient surface cleaning, pipe heating and minimization of alloy layer growth during the immersion step [1].

The galvanizing process mainly consists of surface cleaning and galvanizing operation. For this reason, the steel surface must be cleaned chemically before galvanization [1-4]. To that end, the pipes are prepared for zinc coating through surface treatments such as degreasing, pickling, water rinsing and fluxing. Each of these surface cleaning operations applied has a great impact on the quality of final galvanized surface coating [1]. No matter how much the surface contamination is cleaned by degreasing, pickling and rinsing, some impurities may persist on the component surface to some degree. Inadequate metallurgical treatment of the surface of metal leads to a negatively affected Fe-Zn reaction which would occur when the metal enters the molten zinc bath. Residual compounds like iron oxide on the steel surface cannot be dissolved by acid solutions. Flux not only dissolves and removes from the surface any iron chlorides, sulphates and oxides that may be produced during acid pickling, but also creates a thin crystalline zinc layer on the steel surface. Flux solution is composed basically of zinc chloride and ammonium chloride [20].

Marder [1], Porter [4] and Cook [20] stated that the chemical properties and application methods of flux solution differ according to the dry and wet galvanizing methods. In wet galvanizing, flux is applied on the molten zinc bath and when the material is immersed into the molten zinc bath, it first comes in to contact with the melt flux on the bath surface. The wet process requires less plant equipment and space due to the strong cleansing action of the flux blanket. It is less liable to produce poorly galvanized patches. In general, because of the wiping action, the wet process tends to produce thinner coatings when the workpiece is withdrawn through the flux. Any adherent flux is removed by subsequent water quenching. Alternatively, the flux blanket may be held back so that the article may be withdrawn through clear zinc [1].

In dry galvanizing, after the degreasing and pickling operations, the pipes are immersed in an aqueous flux solution and then dried [6, 8, 17, 21]. The pipes are processed through a drying furnace at temperatures between 60 °C and 120 °C prior to galvanizing and are then immersed in the zinc melt. It is essential that the material be thoroughly dried before immersion in the molten bath. The optimum condition for drying is changed according to the galvanized material and it needs to be precisely determined. Wet patches on the piece can cause spatter and splashing that can result in splash marks and bare patches on the finished part. Materials that have been pre-fluxed and dried should be galvanized immediately, as the flux coating picks up moisture from the air and tends to oxidize [1]. After surface treatments, the material is immersed into the molten zinc bath. Dry galvanizing is more sensitive to surface preparing deficiencies so more care is needed for surface treatments. A higher level of technology and also good control of the operation is required. In dry galvanizing, cleaning efficiency of flux is lower in comparison to wet fluxing. However, the iron salts on the surface of metal transform into iron hydroxide in the alkali flux bath and settle at the bottom of the bath. Thus the transport of iron into the kettle of molten zinc is prevented. The explosion hazard is also more acute in dry galvanizing than in wet galvanizing. The advantage of this method is the technically simple handling of large components and the fact that the galvanized products are relatively free from flux residues [21].

In the dry galvanizing process, as shown in Figure 1, the pipes are chemically treated and then dried in a continuous drying furnace, followed by the galvanizing kettle which has built-on pipe dipping devices. Immediately after the drying process, the pipes are immersed one at a time into the bath of molten zinc by special devices. In conventional applications, the heat inside the drying furnace is supplied by the waste gases in the combustion chamber of the galvanizing kettle and any shortage of energy is compensated for by additional burners being installed in the system. Adequate air circulation inside the furnace must be provided for a rapid and effective drying process. Necessary efforts are made to achieve a uniform temperature distribution inside the furnace by allowing for adequate air circulation using circulation fans. It is quite difficult in conventional drying furnaces to achieve a uniform temperature distribution along the pipe. The temperature of the flue gas that is used for heating purposes is higher when it first enters the drying furnace, decreases as it moves along the surface of the pipe and reaches its minimum value at the time of leaving the pipe. Therefore, the first point of contact between the pipe and the flue gas will be hotter than the end point. Practical applications demonstrate temperature differences up to 15 to 20 °C along a pipe. Such temperature difference either leads to some under-dried parts of the pipe due to low temperature, or to a burned flux layer due to high temperature. If the pipes that come out of the drying furnace are not dry enough, minor eruptions occur on the zinc surface when the pipe enters the bath, which leads to zinc coating defects or impaired quality of pipe surface due to zinc ashes or various non-metallic slags and other residues that exist on the surface of molten zinc bath, adhering to the pipe surface [1]. Increasing the temperature inside the chamber of drying furnace in order to achieve a through-dry on the other hand, results in high temperature gas circulating inside the drying stove and a burned flux layer on the parts of first contact of the hot air with the pipe. No zinc coating is formed on such parts where the flux layer was burned and lost its function, resulting in a galvanizing defect called “black spot” [22]. Black spot is the most common type of defect in practice, which is easily detectable with the naked eye.

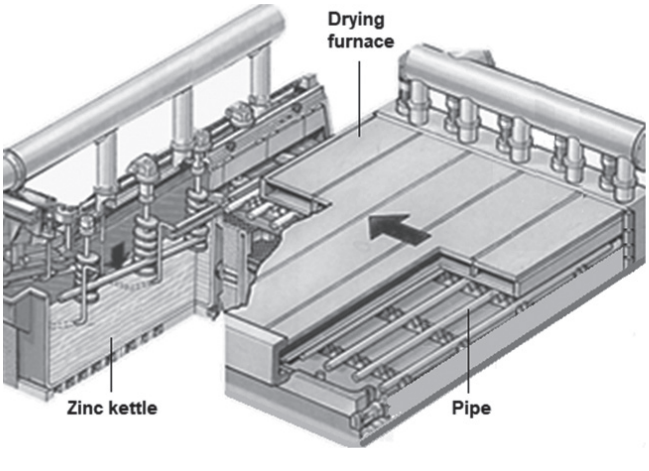

Figure 1: Schematic view of conventional drying furnace

Galvanizing of pipes is carried out by the method of mass production and, if the pipe diameter is changed, the feed rate of the pipe conveyor inside the drying furnace must be changed accordingly to achieve a proper drying. To that end, all the pipes already in the drying furnace must be taken out, in order to empty the furnace and new sized pipes must be loaded into the furnace. Therefore, the time required for pipe size change is quite long in the case of conventional drying furnaces. Additionally, the flux residues accumulated inside the chamber of the drying furnace cause corrosion and damage to the pipe feeding mechanisms, which is another factor that steps up costs and makes operation more difficult, creating the need for maintenance. Excessive length of stay of the pipes inside the chamber of the conventional drying furnace in the event of any failure results in product quality problems. The impossibility of achieving a uniform temperature distribution along the pipe in conventional drying furnaces and the negative impacts thereof on the product quality, as well as high maintenance and operating costs of drying furnaces made it inevitable to search for new approaches for pipe drying.

In this study, drying was conducted in an induction heating process instead of using a conventional drying furnace and the optimum drying temperature for the pipes was determined.

Experimental procedure

In this study, two different sizes of pipes, which were manufactured by the electric resistance welding method conforming to EN 10255-M, were used. The thicknesses of the pipes with specified outside diameters of 60.3 mm and 165.1 mm were 3.6 mm and 5.0 mm, respectively. The material quality of pipes conforms to S195 T, the chemical composition of which is given in Table 1, being classified as Class 1 according to EN 10025-2 in terms of suitability for hot dip galvanizing. The pipes were galvanized according to European Standard EN 10240 [23]. The pipes were degreased in an acidic degreasing bath at ambient temperature for 10 min and subsequently rinsed in water bath and then pickled in HCI solution at a concentration of 15 wt.-% for 15 min to remove impurities such as scales and rust. After pickling, rinsing was performed in water bath and then fluxing was carried out in $ZnCl_2 \times NH_4Cl$ solution at 30 °Be at ambient temperature. The chemical treatment parameters are summarized in Table 2.

After fluxing, the pipes were dried in a conventional furnace and by induction heating to compare the two methods to each other. For conventional drying, an oven with a power of 268 KW and a capacity of 600 kg × h^{-1} was used. The conventional furnace occupied a large space and the size of the furnace was 4.9 m in width, 8.9 m in length and 1.8 m in height. The number of the pipes inside the drying furnace was 20 pieces for 60.3 mm outside diameter pipes and 13 pieces for 165.1 mm outside diameter pipes. Also, times spent in the drying furnace were 346 s and 1040 s for 60.3 mm and 165.1 mm pipes, respectively. The temperature of the flue gas which was circulating inside the furnace was around 180 °C. Just after conventional drying, the pipes were immersed immediately into the bath of molten zinc. Therefore, the temperature measurement was performed only on the outside surface of the pipes by means of an IMPAC Pyrometer IGA 140/23. Temperature measurements were taken from seven different stable points, at each meter of pipe length, and are numbered 0 to 6. Number 6 represents the front edge of the pipe which exits out of the zinc bath first and in the same manner, number 0 represents the rear edge (see Figure 2).

For the drying of the pipes by induction heating, an 300 kW inverter with 3 kHz nominal frequency was used and the heating coils were placed on the roller table along which the pipes that enter the bath of molten zinc. The induction heating system could be adjusted to achieve the desired pipe surface temperature. Continuous temperature measurement was performed along the pipe by using IMPAC Pyrometer IGA 140/23, roughly 4 m away from the induction coil exit. Thus, not only the efficiency of induction heating was continuously monitored but also an attempt was made to determine an optimum pipe temperature required for a flawless galvanized coating formation. While outside temperature measurement was done continuously, for inside temperature measurement, seven holes were created at each meter of the pipe and were numbered 0 to 6. Number 6 represents the front edge of the pipe which exits out of the zinc bath first and in the same manner, number 0 represents the rear edge, similar to the numbering method used in conventional drying (see Figure 2). The schematic representation of induction heating system and heating coil is given in Figure 3. The pipes were dried at different temperatures in order to determine the optimum drying temperature.

Having been dried by induction heating and conventional heating, the pipes were then immersed into a bath of molten zinc at 450 °C, the chemical composition of which is given in Table 3. The capacity of the galvanizing plant was 7 t × h^{-1} and the pipes

C	Si	Mn	P	S	Cu	Ni	Cr	Mo	Al	Fe
0.034	0.011	0.25	0.01	0.01	0.042	0.045	0.028	0.005	0.058	Bal.

Table 1: Chemical composition of pipe material (wt.-%)

	Degreasing	Pickling	Fluxing
Type of chemical	Acidic base	Hydrochloric acid (HCl)	Double salt ($ZnCl_2 \times 2\ NH_4Cl$)
Temperature	Ambient	Ambient	Ambient
Dipping time	10 min	15 min	4 min
Concentration	–	15 %	30 °Be
pH	3	–	4
Fe content	–	180 g · l^{-1}	7 g · l^{-1}

Table 2: Application parameters of chemical treatment

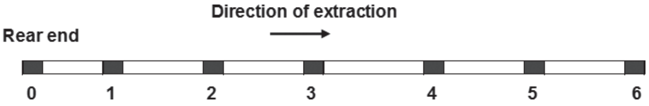

Figure 2: Position of temperature measurements points along the pipe

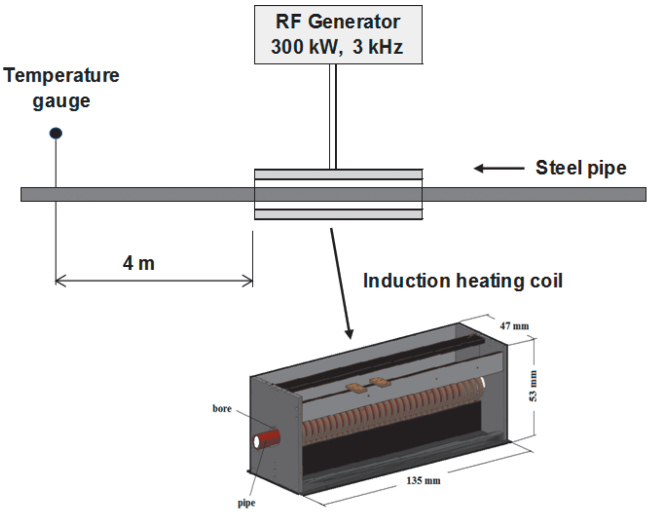

Figure 3: Schematic representation of induction heating system and heating coil

that were kept immersed in the zinc bath at different periods according to the diameters and wall thicknesses of the pipes in a way to maintain such capacity, were taken out of the bath at an angle of 15°. A uniform coating was achieved by wiping away any excess zinc from the outer surface area of the pipes by air jet wiping and by, at the next step, removing any excess zinc from the inner surface area of the pipes by pressure steam jetting at the time of taking the pipes out of the bath according to the diameters and the wall thicknesses of the pipes. Subsequently, the pipes were cooled down in a water bath at 60 °C in order to terminate the Fe-Zn reaction that persisted due to residual heat and might have led to formation of a matte coating with the transformation of pure zinc layer into an alloy layer. Process conditions for galvanizing are given in Table 4 which exhibits the pipe feed rates determined according to the plant capacity of 7 t × h^{-1} and the diameters-wall thicknesses of the pipes.

A group of 60.3 mm and 165.1 mm diameter pipes dried by conventional furnace and by induction heating were taken to measure zinc coating thickness in g × m^{-2} by chemical way according to European Standard EN ISO 1460 [24]. This measurement was done individually for the inside and outside of the pipes. Samples from each pipe were obtained according to Figure 2. In other words, 10 cm long samples were taken out of each meter of pipe length. From each pipe, 7 samples were taken and numbered 0 to 6. Number 6 represents the front edge of the pipe which exits out of the zinc bath firstly and in the same manner number 0 represents the rear edge. After galvanizing, the quality of galvanized surface coating appearance of the pipes which were dried by conventional furnace and induction heating were evaluated. For this purpose, each pipe was divided into 20 cm pieces and all pieces were visually checked to determine if they have black spots or not. In addition, to analyze the galvanized coating structure obtained by induction heating, the specimens were mounted onto a bakelite plate and etched with 2 wt.-% Nital solution. The analysis was performed using a Jeol-jsm-5600 Scanning Electron Microscope (SEM) attached to an Oxford EDS analyzer.

Al	Cu	Pb	Sn	Cd	Fe	Mn	Bi	Sb	As	Zn
0.0013	0.0051	0.0059	0.0033	0.0007	0.0182	0.0003	<0.0003	<0.002	<0.001	99.9513

Table 3: Chemical composition of molten zinc bath (wt.-%)

Pipe size (mm)	Zinc bath temperature (°C)	Dipping time (s)	Air wiping pressure (bar)	Steamblowing pressure (bar)	Pipe feeding rate (m × min^{-1})	Drying temperature (°C)
60.3	450	90	2	8	27	60-70-80-90
165.1	450	140	2	8	7	80

Table 4: Galvanizing process parameters

Table 5: Outer surface temperature measurement results for conventional furnace heating (°C)

Pipe diameter (mm)	Measurement point temperature (°C)						
	0	1	2	3	4	5	6
60.3	63	84	79	84	89	99	93
	70	71	92	85	91	98	89
	79	68	88	85	94	91	88
165.1	84	82	77	86	84	93	96
	79	85	87	77	84	89	88
	74	78	89	92	94	98	93

Table 6: Outer surface temperature measurement results for the 60.3 mm outside diameter pipe at different induction drying setting temperatures (°C)

Set up temperature (°C)	Measurement point temperature (°C)						
	0	1	2	3	4	5	6
60	63	65	60	62	64	59	63
70	72	66	74	72	68	69	74
80	81	77	84	74	80	78	83
90	94	88	94	92	88	91	94

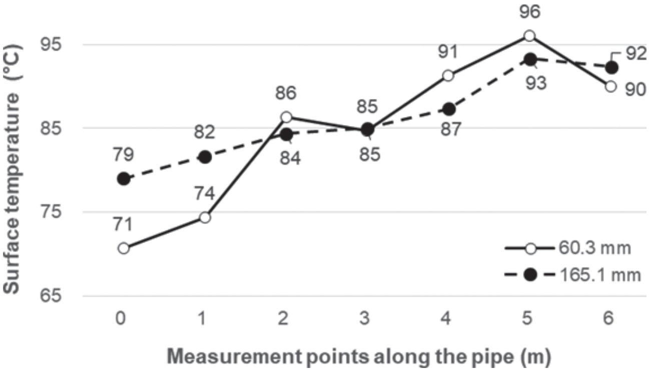

Figure 4: The average outer surface temperature distribution along the pipes, dried by conventional furnace

Results and discussion

As mentioned before, just after conventional drying, the pipes were immersed immediately into the bath of molten zinc. Therefore, the temperature measurement was performed only on the outside surface of the pipes. Thus, 60.3 mm and 165.1 mm pipes, three pieces each, were used and the obtained temperature results are given in Table 5. In conventional applications, the temperature control is done only via the temperature of flue gas which is circulating inside of the furnace. Therefore, it is quite difficult to achieve a uniform temperature distribution along the pipe. The temperature of flue gas that is used for heating purposes is higher when it first enters the drying furnace, decreases as it moves along the surface of the pipe and reaches its minimum value at the time of leaving the pipe. Therefore, the first point of contact of the pipe with the flue gas will be hotter than the end point. From practical experiments, it is seen that there are very large differences in the outer surface temperature along the pipe in conventional heating (see Table 5). In conventional heating, there are high temperature deviations up to 15-20 °C at the average outer surface temperature along the pipe (see Figure 4).

As previously mentioned, 60.3 mm diameter pipes were dried at different temperatures, i. e., 60, 70, 80 and 90 °C, by using induction heating in order to determine the optimum pipe surface temperature for a flawless and high-quality galvanizing process. Outer surface temperature distribution results are given in Table 6. From the table, it seems that the temperature deviation stays between ±5 °C for all set-up temperatures. In visual inspection, when the temperature range was higher than 90 °C, the color of surface turns to a reddish brown and tended to have black spots. On the other hand, in temperatures less than 80 °C, it was observed that there was a high risk of having some locations which were not dry enough. As a result of continuous measurements of the pipe temperature at the induction heating coil exit, the optimum pipe temperature was determined to be 80 °C to avoid any damage to the flux layer due to the overheated pipe surface and to achieve a through-dried inner-outer surface of the pipe. For this reason, all diameter pipes, three pieces each, were dried at a pipe surface temperature of 80 °C and the outer and inner surface temperature distribution results for all pipes are given in Table 7. It is seen from Table 7 that all the pipes were heated uniformly with a tolerance of ± 5 °C by the induction heating process.

The average outer and inner surface temperature distributions along the pipes for 80 °C set-up temperature are given in Figure 5 for all groups of pipes. It is seen from Figure 5 that all the pipes were heated uniformly and the average inside surface temperatures of the pipes appear to be higher than the average outside surface temperature in the range of about 1 to 5 °C. As a result, it is seen that all the pipes were heated uniformly up to 80 °C by the induction heating process applied prior to the galvanizing bath and were allowed to enter the bath of molten zinc in through-dry state and at the optimum temperature for an undamaged flux layer. Thus, the problem of black spots that is very frequently encountered with galvanized pipes and the risk of galvanized coating degradation were completely eliminated and high quality galvanized pipes were produced. It was observed that the galvanized pipes that underwent drying by induction heating had an excellent galvanized coating surface quality and did not produce any defects like black spots that are very common.

As mentioned before, all pipes which were dried by both heating processes were taken to measure the zinc coating thickness in g × m^{-2} by chemical way according

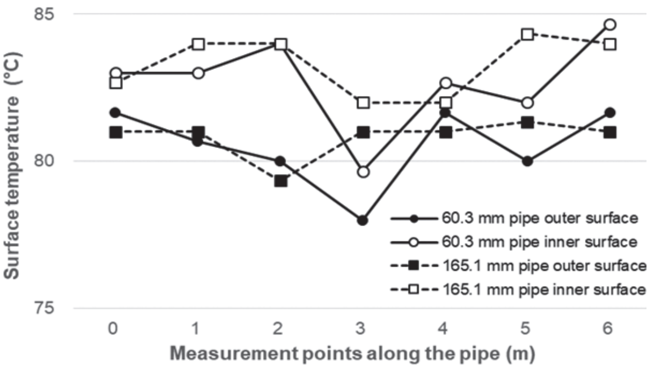

Figure 5: The average outer and inner surface temperature distribution of the pipes at 80 °C set-up induction heating temperature

Pipe diameter (mm)	Pipe surface	Measurement point temperature (°C)						
		0	1	2	3	4	5	6
60.3	Outer	81	77	84	74	80	78	83
		80	83	76	81	84	80	79
		84	82	80	79	81	82	83
	Inner	84	83	86	80	79	83	85
		83	81	87	77	84	81	88
		82	85	79	82	85	82	83
165.1	Outer	84	79	81	76	80	82	81
		80	82	79	84	82	78	80
		79	82	78	83	81	84	82
	Inner	83	81	85	80	83	86	82
		81	84	86	83	81	81	87
		84	87	81	83	82	86	83

Table 7: Pipe outer and inner surface temperature measurement results at 80 °C induction drying set up temperature

Pipe diameter (mm)	Drying system	Pipe surface	Pipe number	Measurement point						
				0	1	2	3	4	5	6
60.3	Furnace	Inner	1	507	561	539	610	499	408	385
			2	563	567	510	676	546	415	372
			3	545	554	528	613	534	462	399
		Outer	1	333	346	280	301	299	310	319
			2	326	322	310	320	359	333	340
			3	327	331	295	321	343	312	328
	Induction	Inner	4	451	559	614	561	676	409	438
			5	416	560	524	676	524	434	421
			6	454	580	561	621	589	442	425
		Outer	4	346	354	302	321	286	318	319
			5	389	325	287	281	305	340	297
			6	348	321	295	306	356	359	309
165.1	Furnace	Inner	7	391	709	855	810	733	736	530
			8	394	646	818	830	777	670	533
			9	493	678	822	798	752	733	632
		Outer	7	491	497	452	407	530	533	543
			8	494	537	415	427	574	467	546
			9	428	481	436	411	532	490	541
	Induction	Inner	10	510	605	721	835	760	712	518
			11	472	780	871	884	711	716	617
			12	481	593	676	831	739	719	588
		Outer	10	610	393	377	432	557	509	531
			11	572	468	468	481	508	513	630
			12	491	471	423	456	503	501	481

Table 8: Zinc coating thickness along the pipe (g × m^{-2})

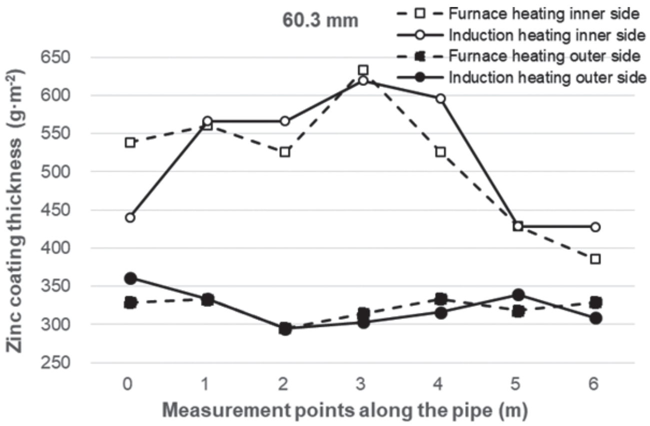

Figure 6: The average zinc coating thickness of the inner surface and the outer surface along the 60.3 mm pipes (g × m^{-2})

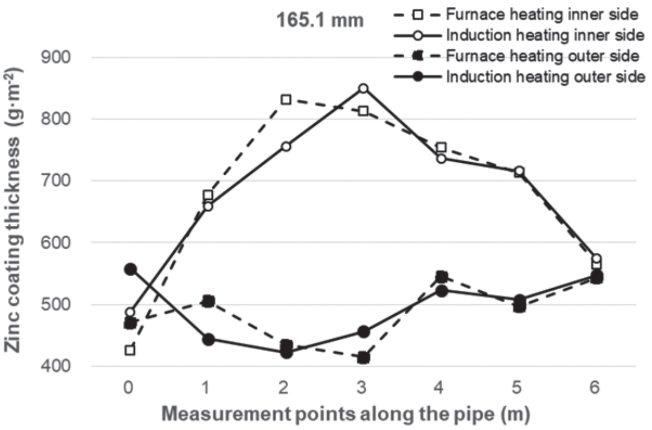

Figure 7: The average zinc coating thickness of the inner surface and the outer surface along the 165.1 mm pipes (g × m^{-2})

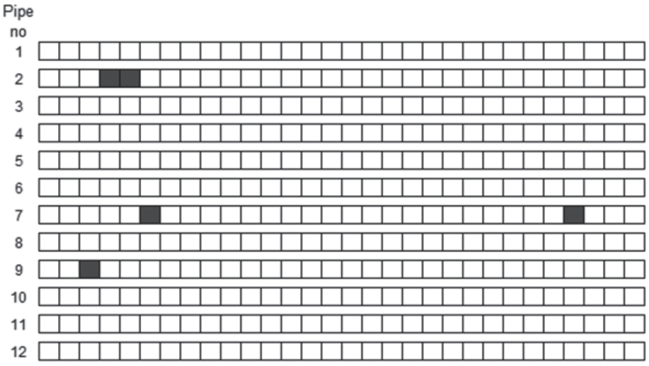

Figure 8: Existing black spots shown as black colour along the pipe

Pipe size (mm)	Pipe surface	Zinc layer thickness (µm)	The thickness of the phases forming the zinc layer (µm)		
			η	ζ	δ
60.3I	Inner	69	44	18	7
	Outer	48	30	13	5
165.1	Inner	100	58	24	18
	Outer	89	45	26	18

Table 9: The thicknesses of the constituent phases of the zinc layer (µm)

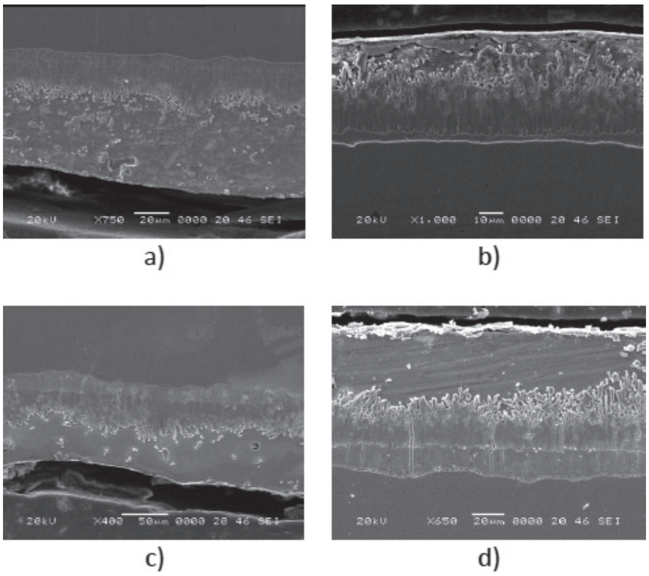

Figure 9: SEM images of the inner and outer surfaces of galvanized pipes of different diameters, a) inner surface, 60.3 mm, b) outer surface, 60.3 mm, c) inner surface, 165.1 mm, d) outer surface, 165.1 mm

to EN ISO 1460. Table 8 shows the zinc coating thicknesses obtained from the inside and outside of all groups in g × m^{-2} for each pipe. The average zinc coating thicknesses of the inner and outer surface of 60.3 mm and 165.1 mm pipes dried by conventional heating and induction heating are given in Figure 6 and Figure 7, respectively. It is noted that inside surface coating thickness is out of standards in some points for the pipes dried in a conventional furnace, while it was on the safe side for induction heated pipes. The standard of EN 10240 requires a minimum of 400 g × m^{-2} zinc coating thickness for the inner surface of the pipes. Also, all pipes were divided into 20 cm lengths as shown in Figure 8, and visually checked on their inside and outside surface for black spots. In Figure 8, pipes no. 1, 2, 3 and 7, 8, 9 show the pipes conventional heating was applied to, i. e., 60.3 mm and 165.1 mm pipes, respectively. Similarly, pipes no. 4, 5, 6 and 10, 11, 12 show the pipes induction heating was applied to. In Figure 8, black spot areas are shown in a black color. It is seen from Figure 8 that black spots are found in pipes no. 2, 7 and 9. All those pipes were dried in conventional drying furnace. On the other hand, it is noted that there are no black spots in the pipes which were dried by induction heating system, as expected.

Coating thickness and structure conform to technical standards. The pipes immersed into the bath of molten zinc at 450 °C were galvanized for different periods of time, according to the diameters and the wall thicknesses of the pipes in a way to maintain the capacity of the galvanizing plant. Galvanized coating thicknesses produced on the inner and outer surfaces of the pipe dried by induction heating and the thicknesses of the constituent phases of the coating in µm were determined by means of EDX and the averages thereof are given in Table 9. The SEM images of the galvanized coatings for inner and outer surface are given in Figure 9. As the period of keeping the pipes immersed in the galvanizing bath was prolonged with the increase of pipe size, total coating thickness also increased. The coatings mainly consisted of the phase η which is called pure zinc. SEM analyses showed that the coating was uniform both on the inner and outer surfaces.

The plant became rather compact and simple by using the induction heating system. In addition, it is expected that the newly installed plants will save space and investment cost. In the case of conventional drying furnaces, if the pipe size changes, all the pipes existing in the drying furnace must be taken out to adjust the pipe feed rate to the new sized pipes, which results in a waste of time. It appeared that none of such troubles that were suffered both at maintenance and at pipe size change in the case of conventional drying furnaces occurred in the case of induction heating drying system. This is because, in induction drying, the pipe comes into contact only with the induction coil and the cleaning and maintenance costs are very low. Also, the change in pipe size includes only a coil change.

Conclusions

In this study, instead of conventional drying furnace, the fluxed pipes were dried at the line by means of induction heating before entering the galvanizing kettle.

The possibility of continuous temperature measurement of the pipes after the drying operation was obtained by applying the induction heating system. That will allow galvanizers to improve control of the operation. By applying the induction heating system, the pipes were heated up much more uniformly than by using the conventional drying method. The temperature changes along the pipe surfaces varied between ± 5 °C by induction heating, whereas by conventional heating the temperatures variations along the pipe outer surface were much greater. There were temperature deviations up to 15-20 °C at the average outer surface temperature along the pipe by conventional heating.

Drying of the pipes by induction heating ensured that the pipes entered the bath of molten zinc at the desired temperature and in through-dry state. By this way, the problem of black spots that is very frequently encountered at the galvanizing plants was eliminated totally by allowing the pipes to enter the molten zinc bath after having been fully dried and heated up to the desired temperature. Thus, high quality galvanized pipes were produced.

The layout for conventional plants with drying furnaces must provide sufficient space for the drying equipment and furnace itself. It is seen that the plant became rather compact and simple with the use of induction heating, i. e., in other words with the removal of conventional drying furnace. Thus, for the new lines, investment cost will be reduced.

In the case of conventional drying furnaces, during the pipe size changing period, all the pipes existing in the drying furnace must be taken out to empty the furnace out in order to adjust the pipe feed rate accordingly and the pipes with new size must be loaded in the furnace, which causes loss of time. However, applying the induction drying system, it is enough to change only the induction coil for the pipe size changing. It is obvious that this kind of quick size change will mean a big advantage that saves time and cost.

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