EVALUATION OF WELDING SEQUENCES FOR PATCHING IN STEEL GEARS

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ABSTRACT

The present work deals with an experimental investigation of the effect of surfacing parameters on the final quality of large gear surfacing. This gear forms a vital part of the drive train of cement furnace at the Iraqi Cement Company. The gear is made of DIN CK 45 steel with an analyzed carbon content of 0.429% and core hardness 185 HV. The gear is considered large, with dimensions of 490 mm in diameter, 250-mm width and 27 mm module, its weight is 350 Kg. The aim of the present work is to study the possibility of repairing this type of gear using SMAW process.

The gear surface is cleaned by sand blasting, followed by dye penetrate testing for crack detections. DIN E1-UM350 hardfacing electrode is selected to hardface the gear. This electrode has a nominal composition (0.08%C, 3.3%Cr, 1%Mn) and a minimum hardness 350 HV. The gear teeth are surfaced with one, two, and three layers with and without preheating. The preheating temperature is 200 C°, which is, selected according to carbon equivalent of the DIN CK 45 base metal.

Cracks were observed in the weld metals when surfacing with three layers of EI-UM350 electrode. So, E 8018-B_2, and E 9018-D_1 are selected to butter the gear surface with one layer, followed by two layers of E1-UM350 electrode. These low hydrogen electrodes are selected based on their mechanical properties compared with DIN CK 45 base metal and low hydrogen content which eliminate hydrogen induced cold cracking. Preheating the gear surface gives good hardness distribution across the weld, HAZ, and base metals due to reducing the cooling rates and prevents hard structure to form at the interface region.

A set of destructive and non destructive tests are carried out. Including, tensile, wear, impact, chemical analysis, metallographic, micro hardness, macro etchent, and dye penetrate tests. Both of wear and impact resistance of all specimens is greater than the base metal. All weld deposits of E1-UM350 hardfacing electrode gives martensitic structures with different hardnesses depending on the cooling rates and number of layers. Using of low hydrogen electrodes (E 8018-B_2 and E 9018-D_1) as buttering layers, solve the cracking problem of weld deposits when surfacing with three layers of E1-UM350 electrodes.

الخلاصة

في هذا البحث تم دراسة إمكانية إصلاح التروس باستخدام تقنية اللحام اليدوي. الترس المستخدم في هذا البحث هو فولاذ متوسط الكربون(DIN CK 45) تم جلبه من شركة السمنت العراقية. يشكل هذا الترس جزء حيوي في منظومة التدوير لافران تجفيف السمنت. نسبة الكربون لهذا الفولاذ 0.429% وله صلادة قلب (185 HV) . يعتبر هذا الترس كبيرا نسبيا حيث يزن 350كغم ،قطره الخارجي 490 ملم ،عرضه 250ملم،و تضمينه 27ملم.

تم تنظيف جميع أسنان الترس بواسطة العصف الرملي ومن ثم فحص الترس بالسوائل النافذة للتأكد من عدم وجود شقوق. أسطح الأسنان هيئت بواسطة تجليخها يدويا. كسيت أسنان الترس بطبقة،طبقتين،وثلاث طبقات مـن سـلك (E1-UM350) باسـتخدام تسـخين مسـبق و بدونـه. التركيـب الكيميـاوي لهـذا السـلك (0.08%C, 3.3%Cr, 1%Mn) وصلادته الدنيا (350 HV) والتي تمثل الصـلادة القصـوى لسـطح أسـنان الترس،وعلى هذا الأساس تم اختيار هذا السلك لإجراء ألا كساء.تم اختيار درجة حرارة التسخين المسبق (200° C) لسطح الأسنان اعتمادا على قيمة الكربون المكافئ.

لوحظت تشققات في منطقة اللحام عند ألا كساء بثلاث طبقات من سلك (E1-UM350). وعليه اختيرت أسلاك لحام واطئة المحتوى من الهيدروجين($E\ 8018\text{-}B_2$ و $E\ 9018\text{-}D_1$) لتزبيد سطح الأسنان ثم تتبع بطبقتـين مـن سلك (E1-UM350). اختيرت هذه الأسلاك لغرض التزبيد لخواصها الميكانيكية الجيدة إذا ما قورنت بالمعدن الأصلي وكذلك محتواها الواطئ من الهيدروجين و بالتالي تضمن عدم ظهور شقوق في منطقـة اللحـام أو المنطقة المتأثرة بالحرارة.

أجريت مجموعة من الفحوصات الاتلافية و غيرالاتلافية لغرض تقييم مناطق اللحام ميكانيكيا و ميتالورجيا. من هذه الفحوصات، فحص الشد،الصلادة المايكروية،مقاومة البليـان،مقاومـة الصـدمة،فحـص السـوائل النافذة،التحليل الكيمياوي،الفحص المجهري،والإظهار ألما كروي.

إن إجراء التسخين المسبق لسطح الأسنان، أعطى توزيع جيد للصلادة خلال مناطق اللحام،المنطقة المتـأثرة بالحرارة، و المعدن الأصلي من خلال خفض معدلات التبريد ومنع ظهور أطوار صلدة في المنطقة المتأثرة بالحرارة. مقاومة البليان والصدمة لمناطق اللحام كانت اكبر من المعدن الأصلي. اظهر الفحص المجهـري لمناطق اللحام لسلك(E1-UM350) بنية المارتنسايت بصلادات مختلفة اعتمادا على معدل التبريـد و عـدد الطبقات. إن إستخدام أسلاك لحام واطئة المحتوى من الهيدروجين كطبقة تزبيد،عالج مشـكلة التشـقق فـي منطقة اللحام.

KEY WORDS

Welding sequences, steel gears, patching, surfacing, preheating, buttering

INTRODUCTION

Gears are vital parts of most pieces of machinery. The techniques for a wide range of gear repair are described below:

1- Using powder welding process to give a wear resistance layer for teeth surface [C.cookson, 1976, 1977, 1979, C.J.Pelser 1978].
2- surfacing the gear teeth by submerged arc welding using low carbon low alloy steel electrodes followed by case hardening (flame hardening or carbo- nitriding depending on the chemical composition of the base metal),[www.retechbg.com, 2001].

In this work, a suitable rebuilding and hardfacing electrodes were selected for gear repair in order to eliminate the subsequent case hardening process (flame hardening and carbo-nitriding) or powder welding process.

EXPERIMENTAL WELDING SEQUENCE

The basic principles incorporated should help to meet almost any gear repair. Gear surfacing is neither mysterious noı complicated if the instructions and recommendations are followed explicitly. The experimental welding sequence used in this research breaks down into five steps:

1- Selection of the base metal of the gear.
2- Selection of hardfacing electrode.
3- Selection of buttering and rebuilding electrodes.
4- Determination of preheating temperature.
5- Experimental surfacing conditions:

SURFACING PROCEDURE:

The steel gear which has the dimensions shown in **Table (1)** is surfaced with E1UM-350 electrode having standard chemical composition shown in **Table (2).** Preheating temperature was selected, 200° C, based on carbon equivalent of the base metal. **Table (3)** indicates the preheating temperature for different types of steel. To prevent cracking, a buffer layers were used before hardfacing especially for high carbon and alloy contents. **Table (4)** indicates the buffering layers used for different types of steel.

Ten specimens of teeth were surfaced with different electrodes with or without preheating as shown below:

1- Surfacing specimen 1 with one layer using E1-UM-350 electrode without preheating.
2- Surfacing specimen 2 with two-layer using E1-UM-350 electrode without preheating.
3- Surfacing specimen 3 with one layer using E1-UM-350 electrode with preheating.
4- Surfacing specimen 4 with two-layer using E1-UM-350 electrode with preheating.
5- Surfacing specimen 5 with one layer of buttering electrode E80180-B_2 followed by two layer of E1-UM-350 electrode without preheating.
6- Surfacing specimen 6 with one layer of buttering electrode E90180-D_1 followed by two layer of E1-UM-350 electrode without preheating.
7- Surfacing specimen 7 with one layer of buttering electrode E80180-B_2 followed by two layer of E1-UM-350 electrode with preheating.
8- Surfacing specimen 8 with one layer of buttering electrode E90180-D_1 followed by two layers of E1-UM-350 electrodes with preheating.
9- Surfacing specimen 9 with three layers of E1-UM-350 electrode without preheating.
10- Surfacing specimen 10 with three layers of E1-UM-350 electrode with preheating.

EXAMINATION AND TESTING

Different apparatuses and tools were used in non-destructive and destructive (static and dynamic) testing in order to evaluate the metallurgical and mechanical properties for surfaced areas and from these were:

- Chemical analysis: chemical analysis was carried out for all specimens including weld and base metals
- Metallographic testing: metallographic testing was carried out for base, HAZ, and weld metals
- Visual and macro-etchent testing: the purpose of this test is to determine the thickness of surfacing layers.
- Liquid-penetrate testing: entire area of the teeth was tested using dye penetrate technique
- Tensile testing: both base metal and buttering electrodes were tested in order to investigate the suitability of these electrodes for buttering this type of steel.
- Micro-hardness testing: three areas was selected for this test, which are, root, contact, and profile areas
- Impact testing: charpy impact test was carried out for specimens having the dimensions shown in **Fig. (2)**

- Wear testing: the evaluations of wear resistance based on determining volume loss of standard specimens having the dimensions shown in **Fig. (3)**.

RESULTS AND DISCUSSIONS

Chemical Analysis

It has shown from **Table (5)** that the carbon content (C%) in base metal (CK45) was (0.423). After surfacing, the migration of carbon from high concentration area to low concentration area has done. This is appear clearly in **Table (6)**, when surfacing with one layer as in the specimen 1&3 with carbon content (0.152&0.167) respectively. When surfacing with two and three layers, the dilution between the base and weld metals was reduced. The carbon content of two layers was varied from (0.126 to 0.131) for specimen 2&4. Also for three layers the content was varied from (0.042 to 0.077) for specimen 9&10. Using buttering technique also reduced the carbon content because the buttering electrodes have a low carbon as shown in the **Table (7)**, which shows the chemical composition of buttering electrodes.

The carbon content was varied from (0.057 to 0.071) for specimen 5&7 and from 0.058 to 0.069 for specimen 6&8, respectively. The standard percentage of chromium in hardfacing electrode was (3.3) and this percentage may be considered as a sufficient amount of chromium to give a martensitic structure on the surface.

It is known that the chromium is α stabilizer, so gives solid solution strengthening. In addition chromium increasing hardenability of steel by reducing the critical cooling rate of transformation. The minimum chromium content was (2.21) for specimen 3 and the maximum content was (4.07) for specimen 9. In general the amount of chromium in specimen 5&7 is greater than specimen 6&8 because chromium molybdenum electrode (E8018-B_2) was used as buttering electrode.

The third important element was manganese, which is γ stabilizer, increases hardenability by reducing critical cooling rate of transformation and increases the toughness of the welds metal. The table shows that the content of manganese, for all specimens, are greater than (1%), which represents the minimum value of standard chemical composition of E1-UM-350 hardfacing electrode. The manganese content was varied from minimum value (1.001) of specimen 7 to maximum value (1.407) of specimen 9. As in the chromium, the manganese content in the specimen 6&8 is greater than specimen 5&7, because the manganese molybdenum-buttering electrode (E9018-D_1) was used as buttering electrode.

Metallographic Testing

Within each composition examined, the description of the microstructures for both weld deposit and heat affected zone is shown in **Fig. (4)** as follows:

1- Surfacing with one layer (specimens 1&3): etching 2% nital revealed a ferrite plus pearlite for base metal [a.], martensitic structure for specimen 1 [c.] and martensitic structure with small amount of ferrite for specimen 3 [g.] in the interface zone while the martensitic structures were observed in the weld metal deposit [b. and f.].

2- Surfacing with two layers (specimens 2&4): in two layers surfacing, the immediately second layer reheat pat of the weld deposit and HAZ metals and thus produce grain refinement. The interface regions for specimen 2 consist of ferrite, fine pearlite and martensite[e.] while specimen 4 consist of ferrite plus pearlite [i.] due to effects of both preheating and subsequent second layer. Again, martensitic structures were observed in weld deposit for both specimens [d. and h.].

3- Surfacing with two layers using buttering (specimens 5, 6, 7 and 8): using of buttering electrodes (E8018-B_2 and E9018-D_1) gives several advantages and from these preventing cracking from formation and forming ductile structure consisting of ferrite plus fine pearlite. The interface region for specimens 5 and 6 consist of ferrite plus pearlite with small amount of martensite [k. and n.]. Ferrite plus pearlite is the structure of interface region for specimens 7 and 8 [q. and t.]

due to preheating and subsequent layers. Martensitic structures were observed for all four specimens, 5, 6, 7 and 8, [j., m., p., and s.]. The microstructure of buttering electrodes for specimens 5, 6, 7 and 8 was ferrite plus pearlite [l., o., r., and u.]. As shown from these figures, the pearlite of specimens 5 and 6 is finer than that of specimens 7 and 8 due preheating to give more time to pearlite to coarsening. Moreover, the subsequent hardfacing layers give refining to buttering layers. The alloying elements, which E8018-B_2 and E9018-D_1 consist of them, improve hardenability and producing a strong and tough acicular ferrite microstructure. Another benefit of buttering electrodes comes from its ability to prevent cracking in weld metal which observed when surfacing with three layers [z.]. This ability of preventing crack formation explained by low hydrogen content of these electrodes (E8018-B_1 and E9018-D_1) which prevent HICC (hydrogen induced cold cracking), in addition to formation a ductile structure (ferrite plus pearlite).

4- Surfacing with three layers (specimens 9 and 10): the microstructure of the interface region of specimen 9, consist of martensite and small amount of ferrite [w.] while the interface region of specimen 10 consist of ferrite plus pearlite [y.]. Martensitic structures were observed for both specimen 9 and 10 [v. and x.].

HICC was observed in the weld metal [z.] and the reasons for this type of crack are:

a- A crack- sensitive microstructure, usually martensitic as in this case.

b- Sufficient hydrogen concentration in the weld as in surfacing with three layers.

Liquid Penetrate Results

The surface of the gear teeth was tested using instructions of the manufacturer. There are no cracks detected on the surface of the gear teeth except specimens 9&10, which they show cracks on the face of the gear teeth. These cracks are also detected by both macro and micro examinations.

Testing Of Base Metal Of The Gear And Buttering Electrodes

Analysis of the gear material reveals it was a medium carbon steel as shown from table (5), which is similar to DIN CK45 steel. Testing of this base metal also showed mechanical properties typical of the aforementioned specification. The buttering and rebuilding low alloy steel electrodes (E8018-B_2 and E9018-D_1) showed the tensile properties in the range of standard mechanical properties of DIN CK45 gear material. As shown from the **Tables (5 & 7)**, both of E8018-B_2 and E9018-D_1 electrodes are very suitable for rebuilding and buttering this type of steel (DIN CK45) from mechanical properties hand.

Macro Etchent Results

Table (8) shows the dimensions of deposit metal for each specimen in addition to preheating temperature. It has shown that the thickness of weld deposit with two and three layers does not equal to double or triple the thickness of weld deposit with one layer. The reason belongs to dilution occurring between the layers.

Micro Hardness Results

It has seen from **Fig. (5)** that the maximum hardness of the surface of base metal is 350 HV [a] at root area. The figures of hardness distribution show the variation of the micro hardness at the surface and in the HAZ in relation to the condition of hardfacing conditions. It seen from figure that maximum micro hardness is measured at the interface region (426 HV) in the specimen 1. While weld deposits of specimens 1 and 3, have a micro hardness (413 & 396 HV), respectively [b.]. The interface region of specimen 3 has a micro hardness of 378 HV, which is lower than that of specimen 1. When surfacing with two layers, the micro hardness of weld and interface regions are reduced. As seen from figure that micro hardness of specimens 2 and 4 are 368 and 358 HV for weld deposit and 309 &254 for the interface region [c.].

In the same figure [d.] and [e.] show the hardness distribution of root area of specimens 5, 6, 7, and 8 respectively. The weld deposits of these specimens have a micro hardness 372, 389, 363, 373, and that for the interface region are 309, 288, 223, 221, respectively. The average hardness of buttering layers (specimens 5, 6, 7, &8) are 236, 234, 208, and 206, respectively.
The weld deposits of specimens 9&10, when surfacing with three layers, have a micro hardness 410 and 407 HV [f.], which are higher than specimens 2, 4, 5, 6, 7, and 8 and similar to specimens 1&3. The micro hardness at the interface region for both the specimens is 321 and 257 HV, respectively. In general, the micro hardness's of all specimens in the root area are higher than that of contact area, [g., h., i., j., and k.], because the two areas have a different thicknesses and this factor (thickness) is reflected on the micro hardness's of these areas.
Also, figures [l. and m.] show the micro hardness distribution across the profile area of the tooth for all specimens. It has seen from these figures that the micro hardness varies with the thickness of the teeth. As the thickness of the teeth decreases from the root to the tip, the micro hardness is decreases also.
From the all of the mentioned above, important point must be discussed here, which is the factors influencing hardness in hardfacing. The hardness developed in weld deposits "as-welded" vary according to the following principal factors:

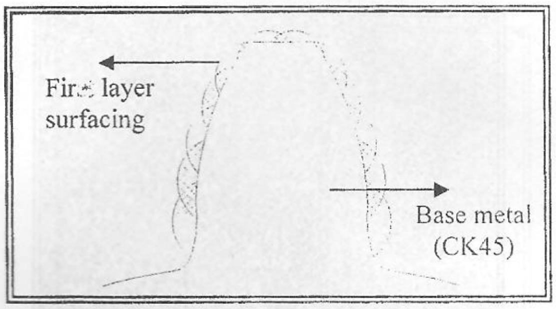
1- Pretreatment such as preheating.
2- Admixture of the base metal with weld deposit (dilution).
3- Rate of cooling: mass and thickness of the object acts upon the rate of cooling.

Impact test results

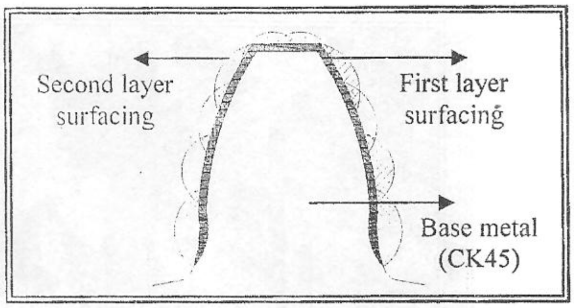
Table (9) shows the results of this test. It has been shown from this table that minimum impact value of the weld deposit was 36 J (specimen 1) when surfacing with one layer. When surfacing with two layers, the impact value raised to 43 J. preheating the teeth surface to 200° C, increase the impact value from 36 J (specimen 1) to 38 J (specimen 3) and from 43 J (specimen 2) to 47 J (specimen 4).
Using buttering technique gives good enhancement to impact values when using E8018-B_2 and E9018-D_1 electrodes as buttering layers. As indicated in the table, the impact values were raised when using buttering in which specimens 5 and 6 gives an impact values 49 J and 51 J.
Again using preheating, raises the impact values to 56 J (specimen 7) and 58 J (specimen 8) respectively. These values represent the maximum values for all cases. The impact values of specimens 9 and 10 are similar to that of specimens 2 and 4.
From the mentioned above, obtaining good weld metal toughness via microstructure control, through optimization of weld chemistry and cooling rate, by means of consumable selection and right weld procedures, respectively.

Wear Test Result

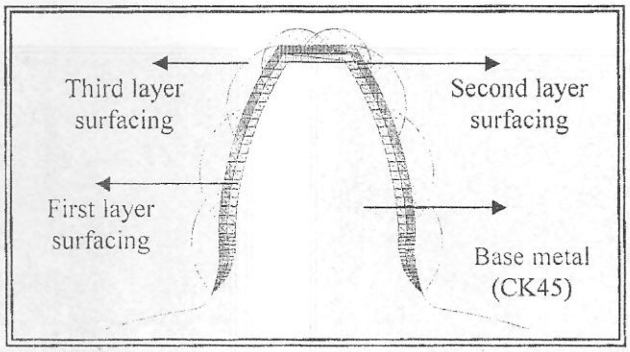
Table (10) shows the result of wear test. It has seen from the table that the lowest volume loss (greater wear resistance) was recorded for specimen 1 (0.451 mm^3) and specimen 9 (0.473 mm^3) and the larger volume loss (lower wear resistance) was recorded for specimen 4 (0.691 mm^3) and specimen 7 (0.652 mm^3).
In general, the wear resistance in this research of all specimens was varied with its hardness i.e. as the hardness increases, the wear resistance increases also. It has shown from **Table (6)** that the specimens 1 &3 have higher carbon content and this reflected on both their hardness and wear resistance, because carbon contents affected the matrix hardness.
Finally, it should be remembered that hardness is not necessarily an indication of wear resistance. As in specimen 9&10, which have higher hardness than other specimen and good wear resistance but these hard deposits were prone to hydrogen, induced cold cracking.



a. Surfacing with one layer.



b. Surfacing with two layers.



c. Surfacing with three layers

Fig. (1) Deposit pattern of surfacing layers.

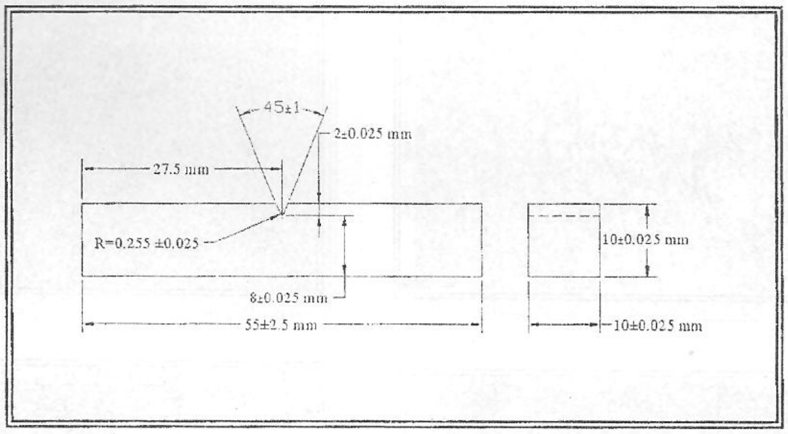


Fig. (2) Standard charpy impact test.

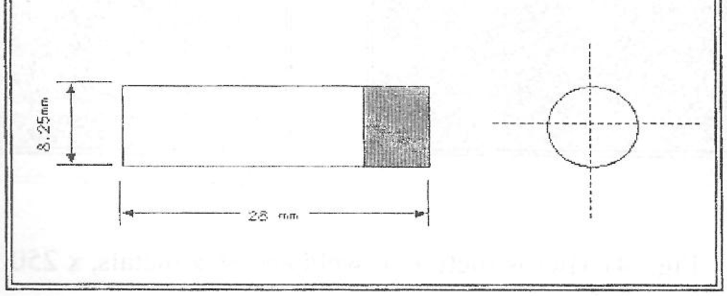


Fig. (3) Standard wear test specimen

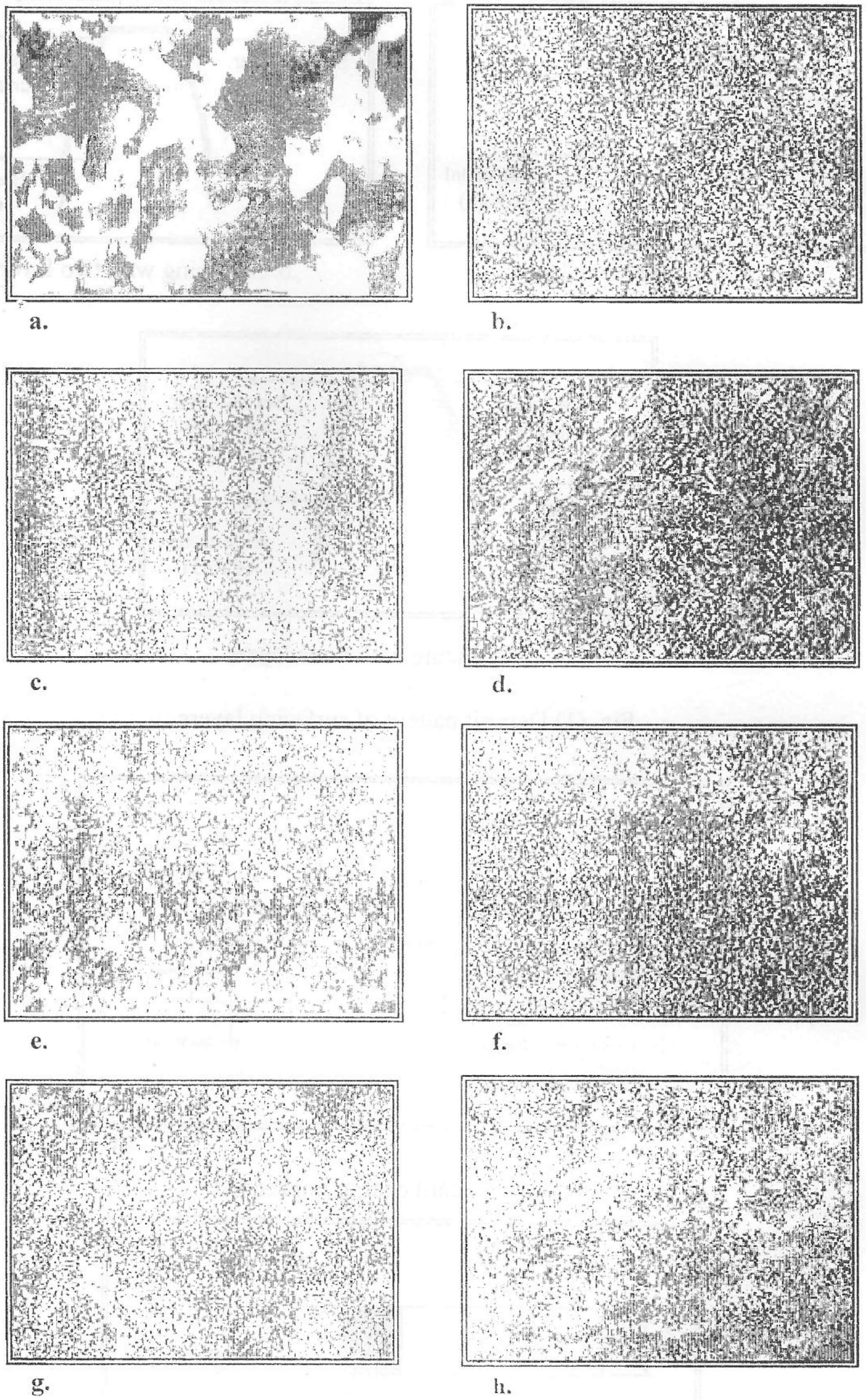


Fig. (4) Microstructure of weld and Haz metals, x 250

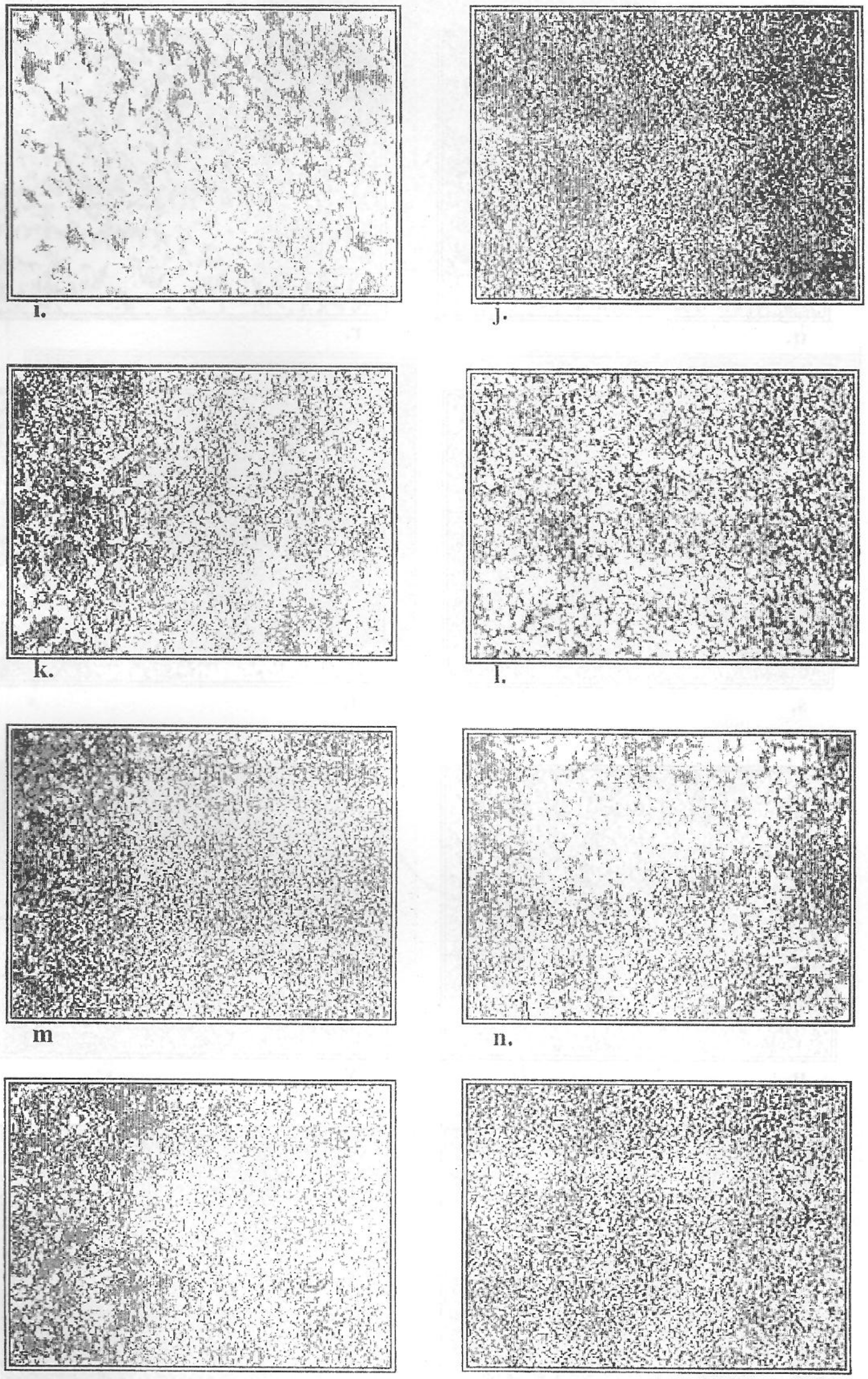


Fig. (4) continued x250

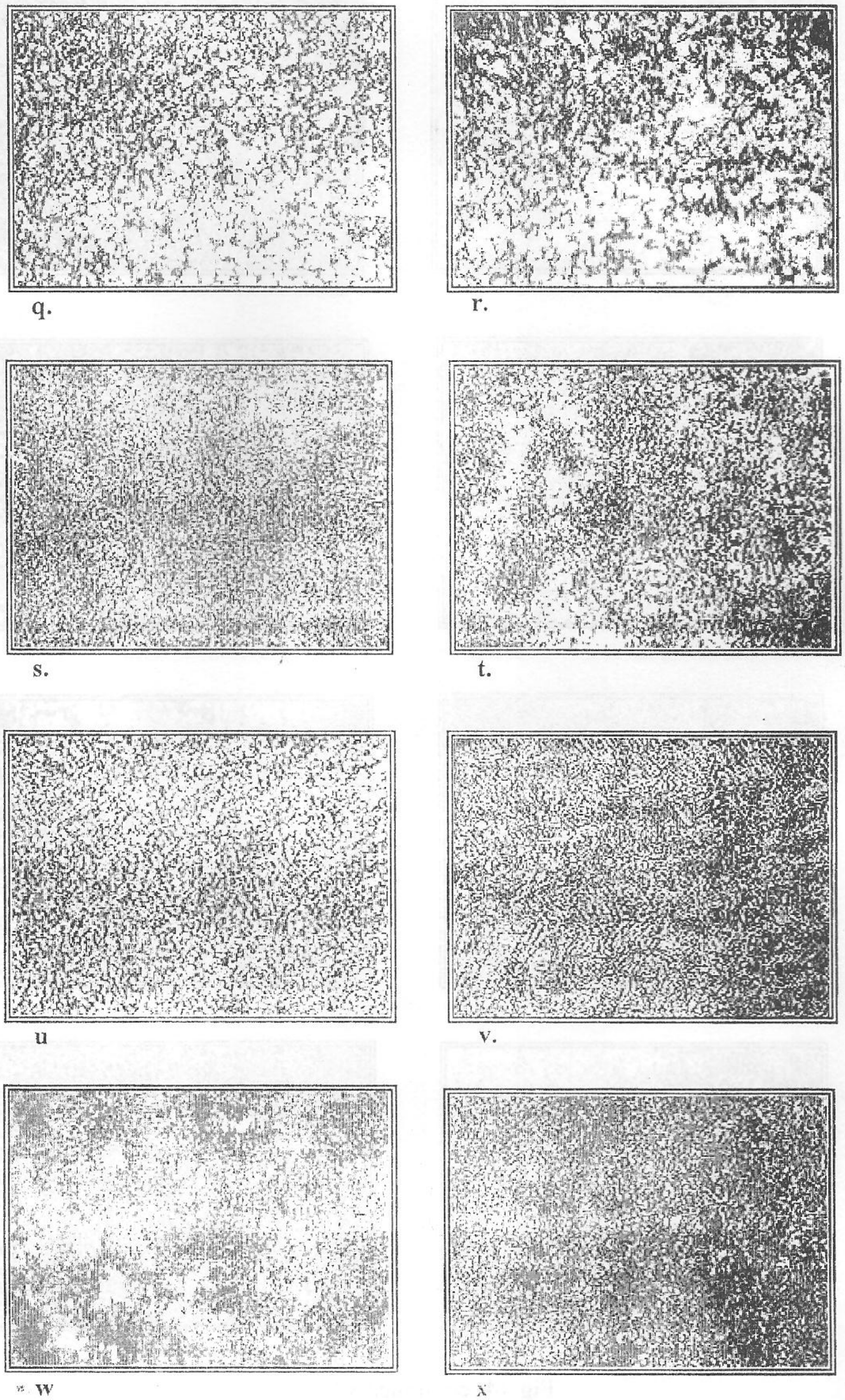
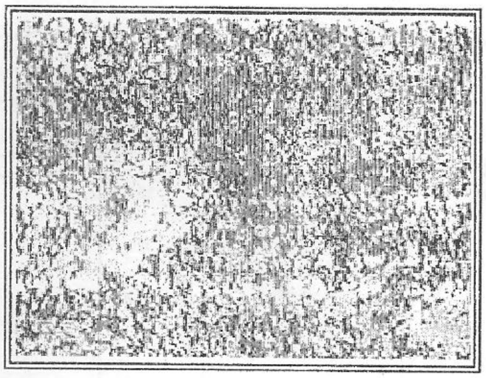
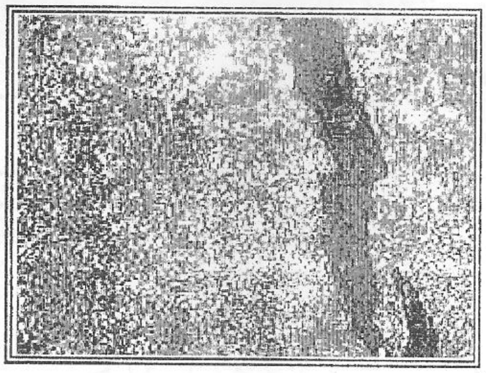
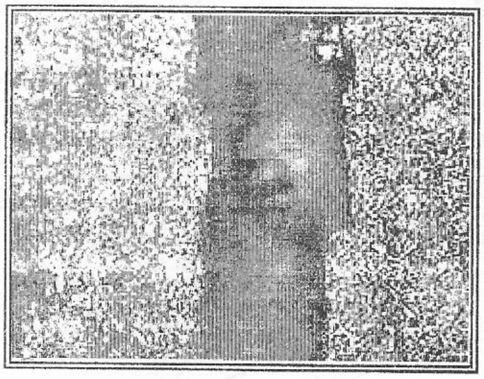


Fig. (4) continued x250



y.





z.

Fig. (4) continued x250

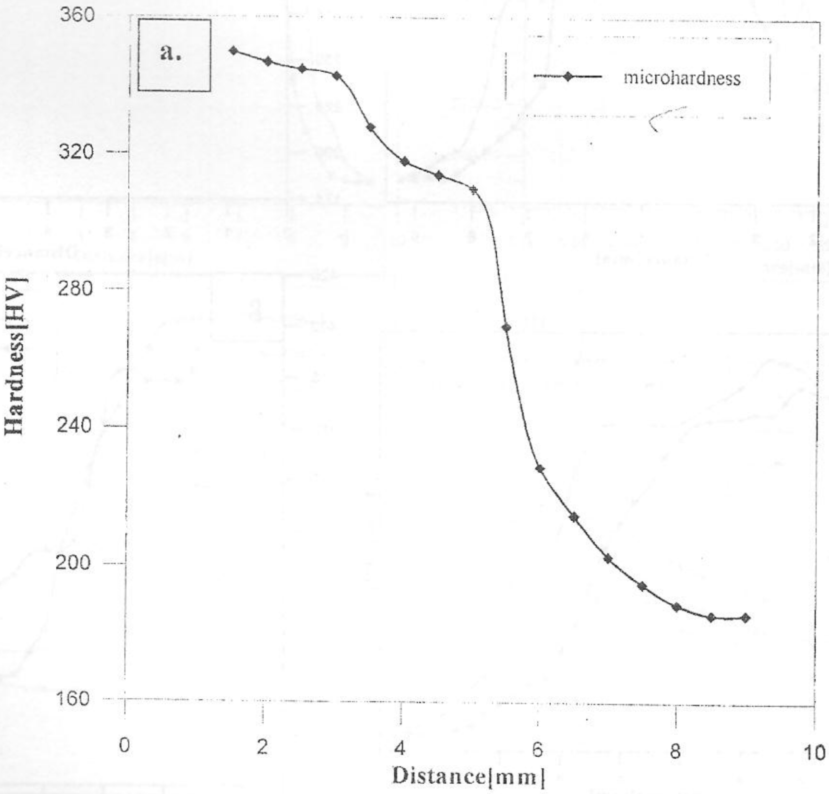


Fig. (5) Micro hardness distribution (from the surface) across root, contact and profile areas of the gear

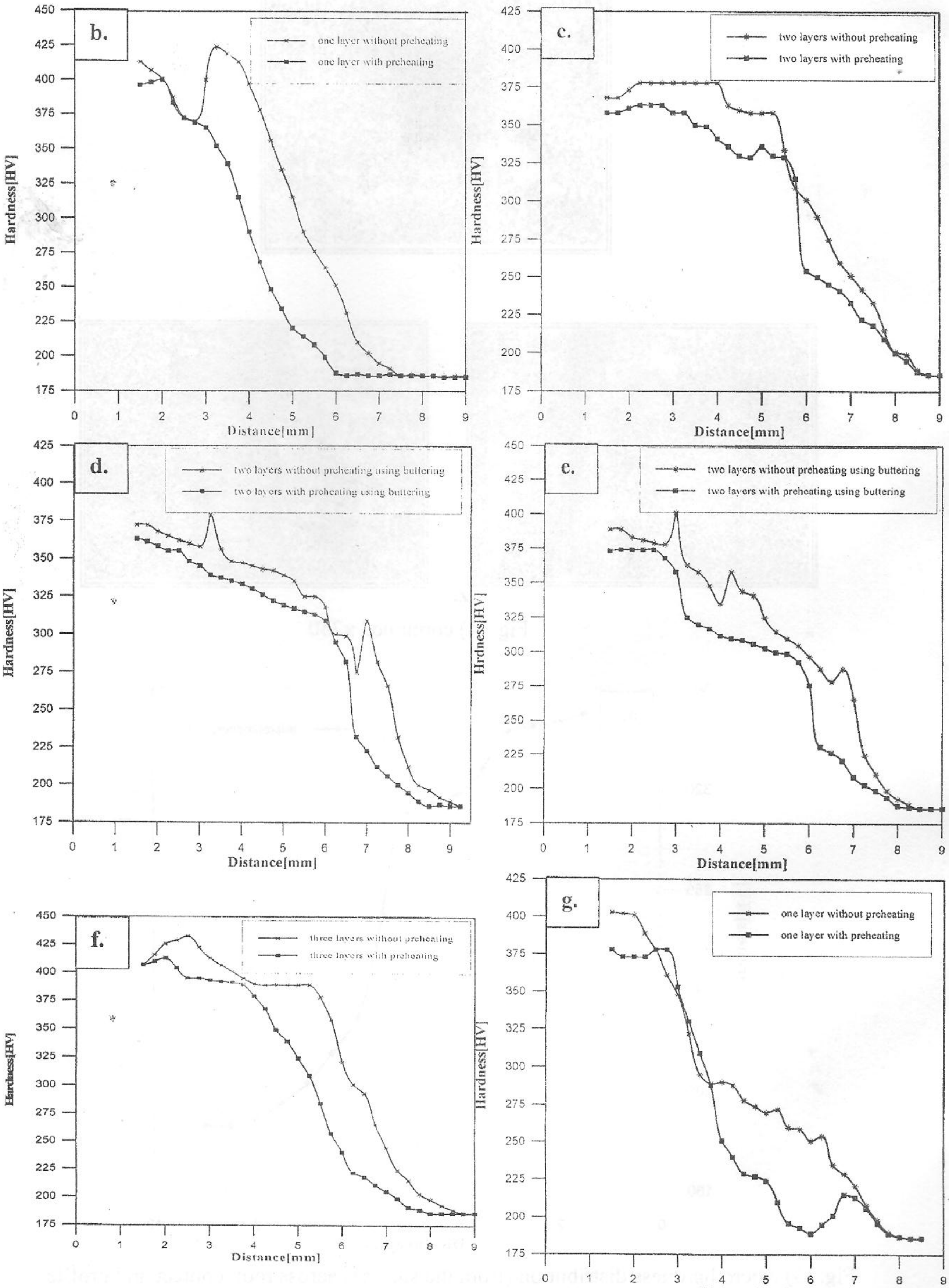


Fig. (5) continued

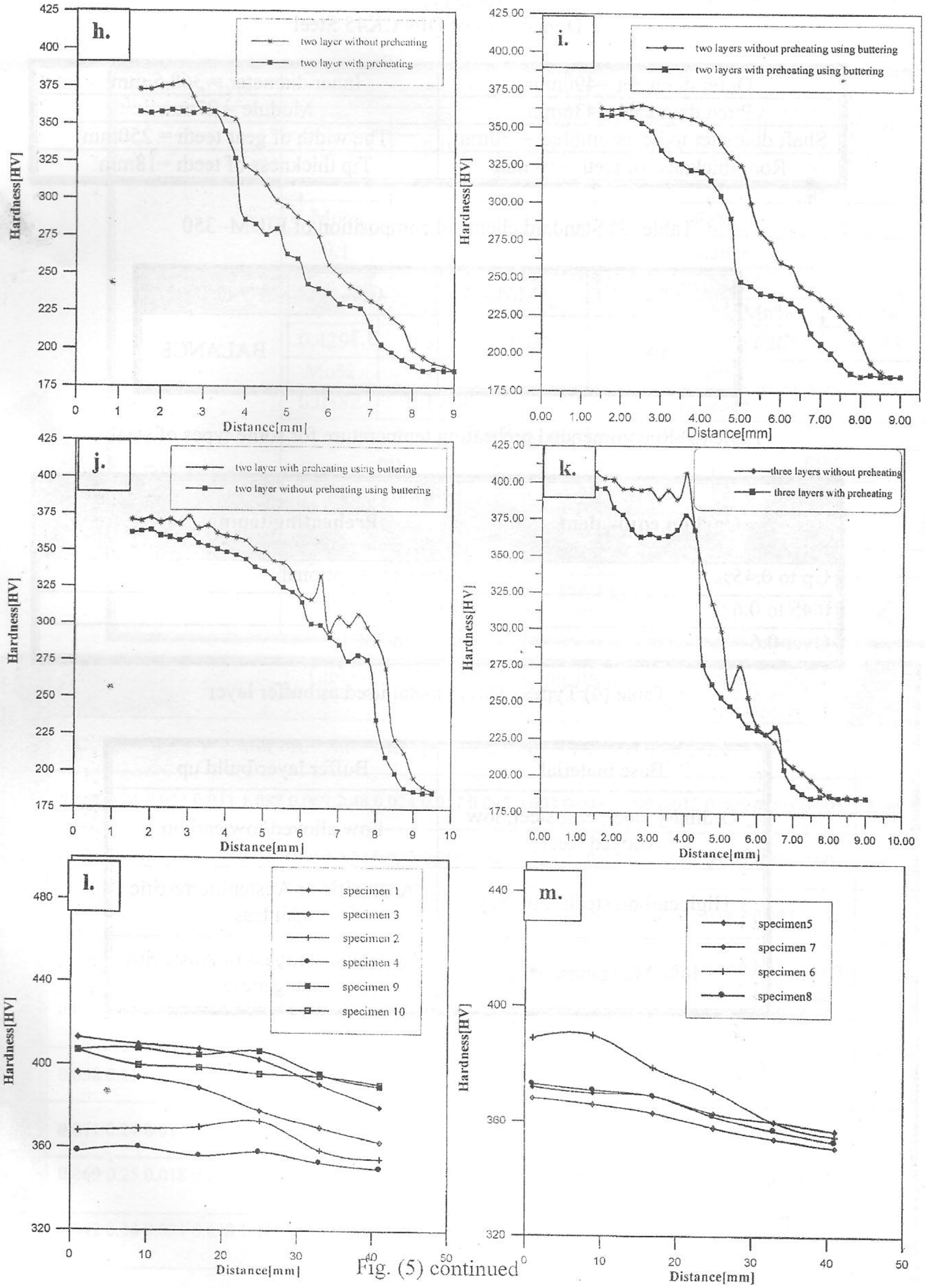


Fig. (5) continued

Table (1)
Dimensions of DIN CK45 Steel

Outer diameter =490mm	Inner diameter = 368.5 mm
Pitch diameter = 436mm	Module = 27mm
Shaft diameter to be assembled =170mm	The width of gear teeth = 250mm
Root thickness of teeth =50 mm	Tip thickness of teeth =18mm

Table (2) Standard chemical composition of EIUM- 350

C%	Mn%	Cr%	Fe%
0.08	1	3.3	BALANCE

Table (3) Recommended preheating temperature for some types of steel

Carbon equivalent	Preheating temperature C°
Up to 0.45%	Preheat is optional
0.45 to 0.6	90 to 200 C°
Over 0.6	200 to 350 C°

Table (4) Types of weld metal used as buffer layer

Base material	Buffer layer/build up
Ordinary steel; cast steel; low Alloyed steel	Low alloyed/low carbon
High carbon steel; tool steel	Austenitic or Austenitic/ferritic stainless
14% Manganese steel	Austenitic stainless or Austenitic manganese

Table (5) standard and experimental chemical composition and mechanical properties of DIN CK 45 Steel gear

Material type	Standard chemical composition analysis					
	C%	Si%	S%	P%	Mn%	Cr%
	0.42-0.5	0-0.4	0.035	0.035	0.5-0.8	0.4
	Mo%	Ni%	Fe%			
	0.1	0-0.4	Balance			
	Experimental chemical analysis					
	C%	Si%	S%	P%	Mn%	Cr%
	0.4291	0.3973	0.012	0.035	0.6265	0.178
	Mo%	Ni%	Fe%			
	0.0382	0.1779	Balance			
DIN CK 45	Standard mechanical properties					
	σu		σy		El%	
	590-710 MPa		>=355 MPa		18%	
	Experimental mechanical properties					
	σu		σy		El%	
	638 MPa		386 MPa		18.5%	

Table (6) Weld metal composition
Chemical composition of weld metals in wgt.%

Specimen no.	C	Si	S	P	Mn	Ni	Cr	Mo	V	Cu	W	Ti	Sn	Co	Nb	Zr	Zn	Fe
1	**0.152**	0.25	0.018	0.011	**1.083**	0.069	**2.48**	0.024	0.017	0.045	0.003	0.008	0.009	0.012	0.006	0.003	0.003	Rem.
2	**0.126**	0.29	0.020	0.014	**1.151**	0.059	**3.54**	0.025	0.018	0.041	0.005	0.006	0.014	0.011	0.006	0.004	0.003	=
3	**0.167**	0.27	0.017	0.019	**1.051**	0.036	**2.21**	0.022	0.026	0.021	0.004	0.008	0.011	0.013	0.009	0.003	0.006	=
4	**0.131**	0.29	0.018	0.022	**1.110**	0.060	**3.29**	0.022	0.026	0.046	0.007	0.010	0.010	0.013	0.009	0.001	0.007	=
5	**0.057**	0.21	0.018	0.012	**1.009**	0.032	**3.58**	0.053	0.020	0.028	0.005	0.007	0.008	0.009	0.006	0.003	0.006	=
6	**0.058**	0.21	0.015	0.018	**1.201**	0.048	**3.24**	0.024	0.027	0.029	0.006	0.014	0.015	0.014	0.009	0.003	0.006	=
7	**0.071**	0.24	0.017	0.020	**1.001**	0.048	**3.51**	0.075	0.027	0.021	0.006	0.015	0.011	0.012	0.008	0.003	0.005	=
8	**0.069**	0.25	0.018	0.021	**1.157**	0.035	**3.16**	0.069	0.026	0.022	0.005	0.011	0.007	0.013	0.009	0.003	0.004	=
9	**0.042**	0.38	0.021	0.028	**1.407**	0.025	**4.07**	0.033	0.031	0.018	0.007	0.012	0.009	0.012	0.012	0.002	0.005	=
10	**0.077**	0.30	0.017	0.023	**1.166**	0.042	**3.69**	0.022	0.028	0.026	0.007	0.009	0.013	0.012	0.010	0.002	0.005	=

Table (7) Standard and experimental chemical composition and mechanical properties of rebuilding and buttering electrodes ($E8018\text{-}B_2$ and $E9018\text{-}D_1$)

Electrode type							
	Standard chemical composition analysis						
	C%	Si%	S%	P%	Mn%	Cr%	
	0.12	0.8	0.04	0.03	0.9	1-1.5	
	Mo%	Ni%	V%	Fe%			
	0.4-0.65	-	-	Balance			
	Experimental chemical analysis						
	C%	Si%	Mn%	Cr%	Ni%	Mo%	Cu%
	0.095	0.66	0.68	1.35	0.06	0.58	0.021
	Co%	Al%	Nb%	Ti%	V%	W%	Fe%
	0.0001	0.001	0.013	0.01	0.011	0.012	Balance
$E8018\text{-}B_2$	Standard mechanical properties (min. values)						
	σu	σy	El%				
	550 Mpa	460 MPa	19				
	Experimental mechanical properties						
	σu	σy	El%				
	623 MPa	474	20				
	Standard chemical composition						
	C%	Si%	S%	P%	Mn%	Cr%	
	0.12	0.8	0.03	0.03	1.25-1.75	-	
	Ni%	Mo%	V%	Fe%			
	-	0.25-0.45	-	Balance			
	Experimental chemical composition						
	C%	Si%	Mn%	Cr%	Ni%	Mo%	Cu%
	0.089	0.72	1.56	0.02	0.04	0.39	0.032
	Co %	Al%	Nb%	Ti%	V%	W%	Fe%
	0.0002	0.003	0.009	0.03	0.021	0.009	Balance
	Standard Mechanical properties (min. values)						
	σu	σy	%El				
$E9018\text{-}D_1$	620 MPa	530 MPa	17				
	Experimental Mechanical properties						
	σu	σy	%El				
	651 MPa	537 MPa	18				

Table (8) Dimensions of surfacing layers

Specimen number	Thickness of hardfacing layers (mm)	Thickness of buttering layers (mm)	Length of deposit metal (mm)	Preheating temperature C°
1	3	-	250	-
2	5	-	250	-
3	2	-	250	200
4	3	-	250	200
5	4	3	250	-
6	4	2.5	250	-
7	4	3.5	250	200
8	3.5	3.5	250	200
9	7	-	250	-
10	6	-	250	200

Table (9) Impact values o f weld deposit

Specimen number	Impact value (J)
1	36
2	43
3	38
4	47
5	49
6	51
7	56
8	58
9	42
10	46

Table (10) Wear resistance of weld deposit

Specimen number	Volume loss(mm^3)
1	0.451
2	0.631
3	0.517
4	0.691
5	0.612
6	0.523
7	0.652
8	0.582
9	0.473
10	0.494

CONCLUSIONS

In the process and power generation industries, down time of mechanical equipment means increase costs and lost revenue, thus the minimization of down time is a major priority. In addition, the increased costs of the replacement have become a major part of plant maintenance budgets, which are under very close scrutiny. This research shows the technical feasibility of DIN CK 45 spur gear repair using shielded metal arc welding (SMAW).

The results, based on the investigations, confirm the effect of surfacing parameters on the metallurgical and mechanical properties of E1UM-350, E 8018-B_2, and E 9018-D_1 deposit metals used for surfacing DIN CK 45 steel gear, validates the following conclusions:

1- DIN CK 45 spur gear can be hardfaced with DIN E1-UM350 electrodes.
2- It is essentially to preheat the gear surface to 200 C° for this type of steel.
3- Wear resistance of all specimens is greater than the base metal.
4- Impact resistance of all specimens is greater than the base metal.
5- The considerable increase in the micro hardness at the interface region, especially specimen1, is a result of austenite to martensite transformation.
6- Surfacing with two-layer gives self-tempering in the HAZ area especially with preheating.
7- The cracks have been shown in the weld metal when surfacing with three layers and the reason may be accumulate of hydrogen gas in the weld metal and give HICC when the weld metal has been solidified.
8- It possible to butter and rebuild this type of steel gear by E 8018-B_2 and E 9018-D_1 electrodes, followed by two layers of E1-UM350.
9- 9. Using of low hydrogen electrodes such as E8018-B2 and E9018-D1, as rebuilding and buttering layers, treat the problem of cracking of weld metal that has been mentioned above.

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