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Alternative welding reconditioning solutions without post welding heat treatment of pressure vessel

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Abstract. In pressure vessels, working on high temperature and high pressure may appear some defects, cracks for example, which may lead to failure in operation. When these nonconformities are identified, after certain examination, testing and result interpretation, the decision taken is to repair or to replace the deteriorate component. In the current legislation it's stipulated that any repair, alteration or modification to an item of pressurised equipment that was originally post-weld heat treated after welding (PWHT) should be post-weld heat treated again after repair, requirement that cannot always be respected. For that reason, worldwide, there were developed various welding repair techniques without PWHT, among we find the Half Bead Technique (HBT) and Controlled Deposition Technique (CDT).
The paper presents the experimental results obtained by applying the welding reconditioning techniques HBT and CDT in order to restore as quickly as possible the pressure vessels made of 13CrMo4-5. The effects of these techniques upon the heat affected zone are analysed, the graphics of the hardness variation are drawn and the resulted structures are compared in the two cases.

1. Introduction

Continued usage, repair or replacement of pressure vessels and structures as related to life extension must begin with detailed and specific knowledge of the metallurgical / material condition of the pressure vessel or structure. This type of complete engineering assessment of existing structures must be conducted before any run, repair or replacement decisions can be made [1].

Components operating at high temperature or harsh working conditions are subjected to different failure regimes which require special consideration. In scheduled shutdowns, critical components are inspected and if necessary either replaced or repaired. Generally, the cost effective choice is to extend the life of aged components by repair rather than replacement [2].

Repair welding maybe carried out using a range of welding techniques depending on the nature of the repair. Commonly, most weld repairs require post weld heat treatment (PWHT) to restore the deteriorated metallurgical and mechanical properties. However, critical issues in the course of PWHT such as time, component geometry and unsupported loading during the time the component is hot, mean that it is not always possible to carry out the full procedure. Duration of hold time during the PWHT cycle can be very long especially for thick walled components which result in the extension of the unit downtime [3].

At the moment, in order to repair by welding various components from different industries, several methods are used among which we mention [3]:

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- Half-bead technique, used widely by different industries for repairing different alloys such as 2.25Cre1Mo steel. At first, this technique has been developed in the nuclear industry, but it became one of the most applied repairing techniques in all the industrial fields that presuppose welding procedure [4, 5];
- Temper bead, the heat input of the subsequent layer in the TBW technique is increased in order to able to refine the coarse grain or temper the martensitic/ bainite microstructure of the HAZ.
- Cold repair is the repair process which eliminates the need of preheat or PWHT hence time saving in a shutdown repair can be significant;
- Consistent Layer Technique. In applying this technique there can be used either the method of shielded metal arc welding, or the TIG procedure, with wolfram inert gas. This technique consists in depositing small enough layers, so that the next deposited layer has only the tempering effect on the heat affected zone HAZ which arises from depositing the previous layer, figure 1;
- Alternate Temper Bead Technique, This technique was developed especially for the classes of steel C-Mn, C-Mo, used in nuclear reactors for the components of products under pressure, [6];
-Controlled Deposition Technique, This technique resulted from special cases where the inter-crystalline corrosion and the reheat cracking may manifest during the repair. The procedure shielded metal arc welding is used and it consists in increasing the linear energy with a certain percentage, between 1.2 and 1.7, from one layer to another [6, 7], figure 2;
-Weld Toe Tempering Technique. This technique involves depositing a layer or a passage of heat treatment on the surface of the welding joint to ensure the tempering of the HAZ created by depositing the previous layer. The mode of deposition is very important in order to achieve this requirement [8], figure 3.

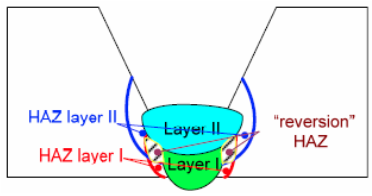

Figure 1. Application scheme of the consistent Layer Technique, [9].

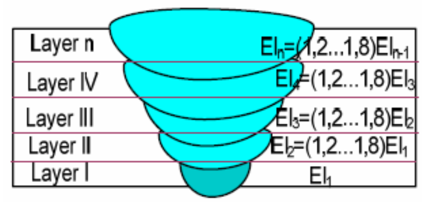

Figure 2. Application scheme of controlled deposition technique.

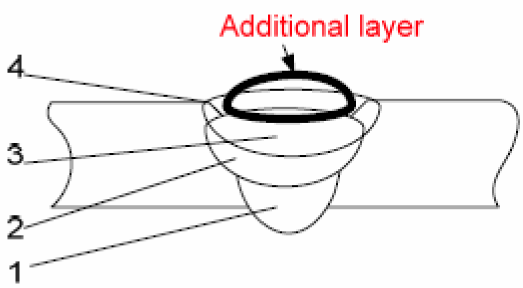

Figure 3. Application scheme of "Weld Toe Tempering Technique"
1 – Layer of root; 2 –filling layer; 3 –closure layer; 4 – layer of heat treatment.

The most common welding process, used in welding repairing, applied to recipient type products is manual metal arc welding [10, 11], because of its ease of applying and relatively low costs.

There is also a number of researches which seek to replace the manual metal arc welding repairing with other more productive processes, such as gas metal arc welding (GMAW) and flux cored arc welding (FCAW) [12, 13, 14, 15]

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2. Experimental Work

The base material, used within the experiments, is SA387 Grade 22 Class 2 Steel, 16 mm thick, in form of sheet, mainly used in the energetic, chemical and petrochemical industry.

The SA387 Grade 22 Class 2 samples were taken from a disposed container which functioned for a long period of years in the energy industry.

For this reason, before the experiments, the real chemical composition of the samples was determined, using the spark method. The obtained results are presented in table 1.

Table 1. Chemical composition of the steel used within the experiments **-** comparison with the average chemical composition mentioned in the steel standard.

Test	Test 1	Test 2	Test 3	Test 4	Test 5	Average	Average value[b]	Difference[c]
C [%]	0.108	0.136	0.0857	0.0914	0.0855	0.10132	0.105	0.00368
Si [%]	0.491	0.495	0.48	0.474	0.485	0.485	0.29	-0.195
Mn [%]	0.485	0.488	0.488	0.483	0.49	0.4868	0.54	0.0532
Cr [%]	1.35	1.34	1.36	1.33	1.34	1.344	0.955	-0.389
Mo [%]	0.437	0.467	0.429	0.427	0.447	0.4414	0.475	0.0336
Ni [%]	0.141	0.122	0.151	0.138	0.132	0.1368	0	-0.1368
Al [%]	0.023	0.0234	0.0259	0.0219	0.0234	0.02352	0	-0.02352
Co [%]	0.0091	0.0097	0.0091	0.0091	0.0091	0.00922	0	-0.00922
Cu [%]	0.0699	0.0691	0.0751	0.0693	0.073	0.07128	0	-0.07128
Nb [%]	0.0031	0.004	0.004	0.003	0.0045	0.00372	0	-0.00372
Ti [%]	0.0038	0.0056	0.0044	0.0041	0.0047	0.00452	0	-0.00452
V [%]	0.005	0.0061	0.0042	0.0056	0.0049	0.00516	0	-0.00516
Sn [%]	0.0088	0.0082	0.0097	0.01	0.0086	0.00906	0	-0.00906
Zr [%]	0.01	0.0031	0.0051	0.0035	0.0024	0.0045	0	-0.0045

[a] The average of the 5 tests
[b] In accordance with ASTM A387/ SA387
[c] Calculated with the formula: Dif. =VMS – Med

Analysing table 1, it can be seen that after a functioning period, changes occur, meaning the increasing or decreasing of the percentage values corresponding to the chemical elements from the material. Moreover, in the conducted tests, other chemical elements were highlighted, such as Ni, Co, Cu, Nb etc., that could not be found initially in the chemical composition of the analysed steel.

In order to apply the 3 methods mentioned above, normal deposit (N), half layer deposit (HBT) and controlled deposit (CDT), the samples were provided with canals, having the following dimensions: 10mm depth, 10 mm width and 100mm length. The samples resulted after processing are presented in figure 4.

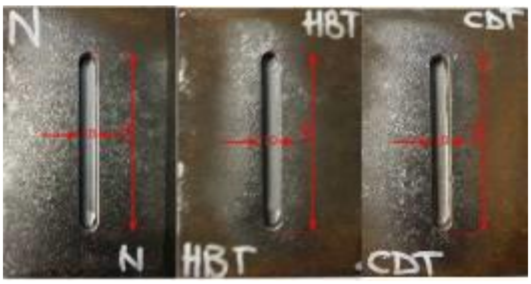


Figure 4. The canals of the N, HBT and CDT samples (canal depth: 10 mm).

The welding repairing process was robotic gas metal arc welding (GMAW), using 1.2 mm GCrMo1Si wire filler material and CO2+18%Ar protection gas.

The welding repairing process parameters, established in accordance with the recommendation of the base material producer, are indicated in table 2.

Because the thickness of the sample in the area of the canal was only 6mm, the first layer was deposited with lower parameters values in order to eliminate the risk of piercing the sample.

Table 2. The welding repairing parameters used in the experiments.

No.	Sample code	Technique	Layer	Parameters used for deposit				
				I_s [A]	U_a [V]	v_s [cm/min]	E_l[a] [kJ/cm]	Gas debit [l/min]
1	N	Normal deposit	1	180	18	35	5	18
			2 - n	260	25	35	10.03	
2	HBT	Half layer deposit	1	180	18	35	5	
			2-n	260	25	35	10.03	
3	CDT	Controlled deposit	1	180	18	35	5	
			2	260	25	35	10.03	
			3	260	25	25	13.76	
			4	260	25	15	22.93	

[a] The heat input was calculated with equqtiojn 1

$$E_l = 60 \cdot \eta \cdot \frac{U_a \cdot I_s}{v_s \cdot 1000} \text{ [kJ/cm]} \tag{1}$$

Where: η- Process yield (0.9 for MAG); U_a – Arc voltage [V]; I_s – Welding current [A]; v_s – Welding speed [cm/min].

The removal of the half-layer, needed in order to successfully apply the HBT technique, was made with a 650W straight grinder with carbide milling cutters and variable speed.

3. Results and Discussion

The predetermined welding repairing parameters (see table 2) were monitorized during the experiments by direct reading on the display of the source. The values are presented in table 3.

Table 3. The welding repairing parameters recorded in the experiments.

No	Sample code	Tech-nique	Layer	Parameters					Deposit height [mm][d]	Layer height after removal [mm][d]
				Is[a] [A]	Ua[a] [V]	Vs[b] [cm/min]	El[c] [kJ/cm]	Debit gaz Dg[l/min]		
1	N	Normal deposit	1	180	17.6	35	4.89	18	1.39	NA
			2	260	24.6	35	9.87		2.99	NA
			3	262	24.6	35	9.94		3.09	NA
			4	261	24.7	35	9.95		3.11	NA
			5[e]	260	24.7	35	9.91		3.07	NA
2	HBT	Half layer deposit	1	180	17.7	35	4.92		1.41	-
			2	263	24.5	35	9.94		3.34	1.7
			3	262	24.5	35	9.90		3.13	1.5
			4	261	24.6	35	9.91		3.28	1.66
			5	261	24.5	35	9.87		3.07	1.58
			6	260	24.5	35	9.83		2.96	1.49
			7[e]	260	24.5	25	13.76		3.89	NA
3	CDT	Controlled deposit	1	180	17.6	35	4.89		1.41	NA
			2	261	24.5	35	9.87		3.04	NA
			3	262	24.7	25	13.98		3.9	NA
			4[e]	260	24.6	15	23.03		4.45	NA

[a] determined as the average between the minimum and maximum values read on the display during the experiments
[b] Value imposed by the robotic system;
[c] Value calculated with relation 1;
[d] Value determined with the average of 3 values determined as the distance from the base materials surface to the height of the deposit;
[e]closure layer;

Sample pictures taken during and after the repair by welding, are shown in figure 5.

a) b) c)

Figure 5. Images taken during and after finishing the experiments:
a) Positioning of the welding gun; b) Layer 2 after the mechanical processing – Sample HBT;
c) The resulting samples.

After cooling the samples to room temperature, wide strips of 25 mm were taken from the central area and processed for the macroscopic analysis and the hardness measuring.

After obtaining the macroscopic images with the help of a software the following characteristics were measured (figure 6):

- Welded seam width, B;
- reinforcement, h;
- penetration, p;
- Welded seam width, measured at the half of the base material thickness, LB.

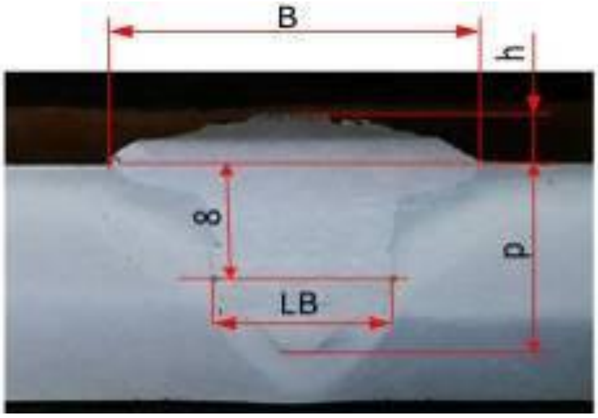
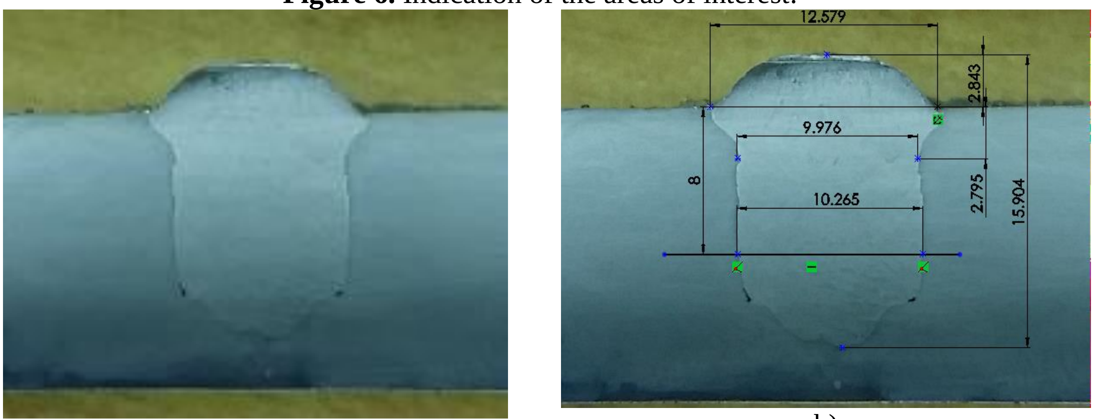
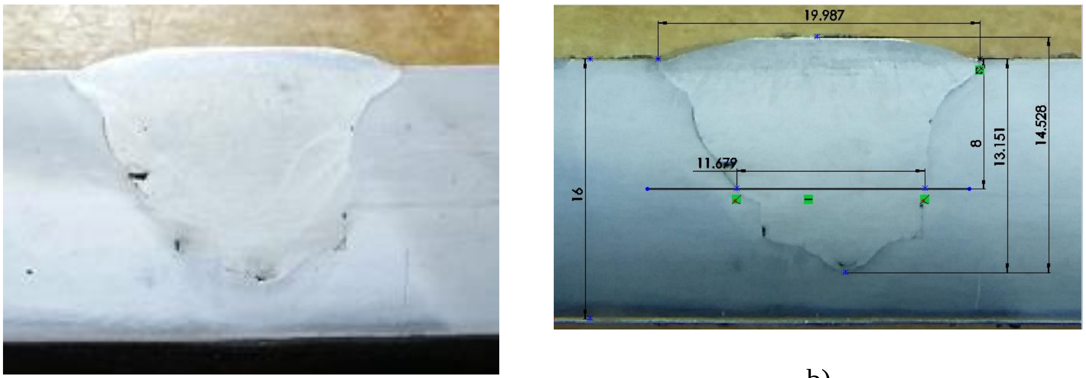


Figure 6. Indication of the areas of interest.



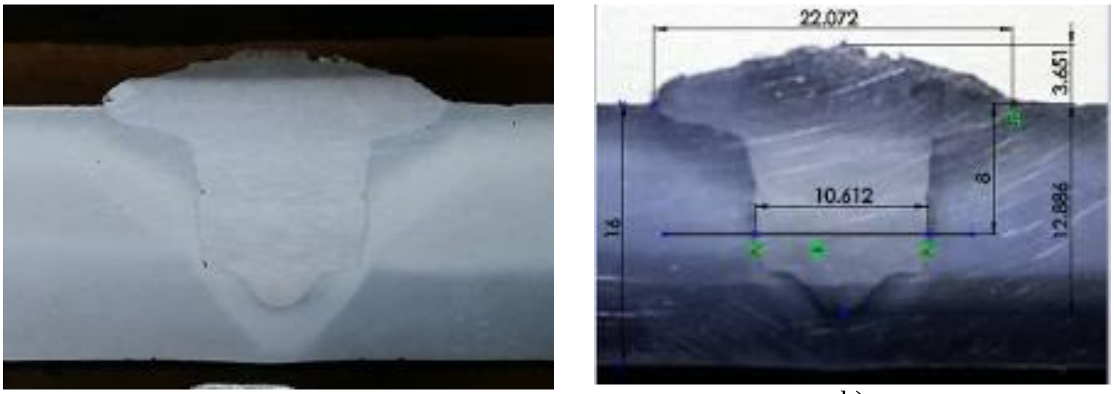
a) b)

Figure 7. The dimensions of the area of interest – Sample N:
a) Macroscopic image; b) Image generated by the soft.



a) b)

Figure 8. The dimensions of the area of interest – Sample HBT:
a) Macroscopic image; b) Image generated by the soft.



a) b)

Figure 9. The dimensions of the area of interest – Sample CDT:
a) Macroscopic image; b) Image generated by the soft.

Obtained results after the measurements, as it can be seen for each sample in figures 7, 8 and 9, are presented in table 4.

Table 4 Welded seams geometrical characteristics.

Measured characteristic	N	CDT	HBT
B[mm]	12.579	22.072	19.987
p [mm]	15.904	12.886	13.151
h [mm]	2.843	3.651	1.377
LB[a] [mm]	10.2365	10.612	11.679

[a] Values measured in the base material at a depth of 8 mm from the surface, see figure 6

Reconditioning methods for analysing the effects of welding applied were determined in accordance with figure 10, the resulting hardness values in each 5 points distinct positioned in the base material, influenced the mechanical stitch.

For analysing the effects of the applied methods of reconditioning by welding, there were determined the hardness values, in five distinct points, in the base material, the HAZ and in the welded seam (see figure 10).

The measurement was carried out on the two directions, I and II, in accordance with Figure 10, and the results obtained are indicated in table 5.

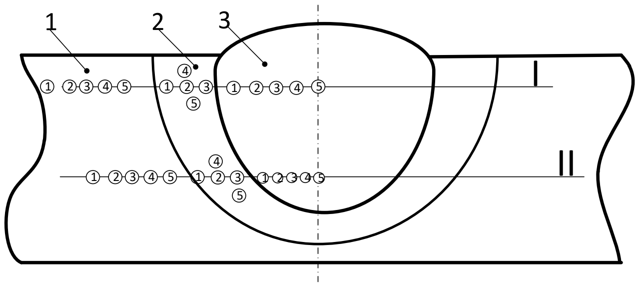


Figure 10. Localization of the measurement points for hardness 1- base material; 2 – heat affected zone; 3 - welded seam; I, II – directions of measurement for hardness.

Table 5. Obtained hardness values on the two directions for the three samples.

Zone[a]	Measurement point[b]	Obtained values on the measurement direction**					
		Sample N		Sample HBT		Sample CDT	
		I	II	I	II	I	II
1	1	313	328	250	232	359	223
	2	298	297	265	229	357	227
	3	294	289	243	220	349	226
	4	280	282	221	212	341	223
	5	276	277	231	223	337	220
	Average	**292.2**	**294.6**	**242**	**223.2**	**348.6**	**223.8**
2	1	307	324	275	223	354	293
	2	305	308	287	225	353	305
	3	304	307	289	214	348	325
	4	299	299	272	217	332	256
	5	287	289	292	227	330	299
	Average	**300.4**	**305.4**	**283**	**221.2**	**343.4**	**295.6**
3	1	272	250	269	244	298	289
	2	268	245	264	246	296	277
	3	263	230	269	243	291	291
	4	256	231	246	249	291	295
	5	257	236	247	244	280	300
	Average	**263.2**	**238.4**	**259**	**245.2**	**291.2**	**290.4**

[a] according to figure 10
[b] HV 0.2 values

The graphical representation of the variation of hardness on the two directions presented in figure 6, it can be observed in the following figures. The figures 11 and 12 present the variation of the hardness average values for all samples taken in the base material, the HAZ and the welded seam.

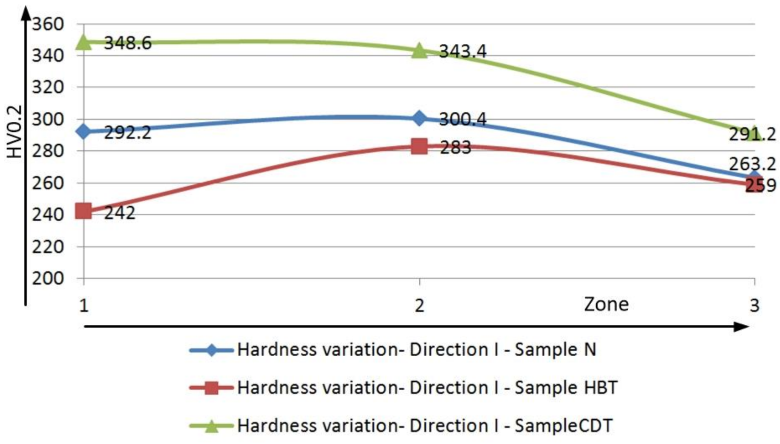


Figure 11. The variation of the hardness average values on the direction I, in the base material, in the HAZ and in the welded seam - for all samples.

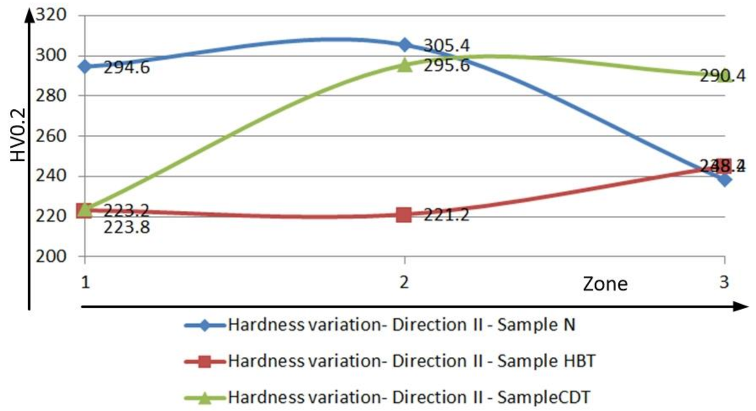


Figure 12. The variation of the hardness average values on the direction II, in the base material, in the HAZ and in the welded seam - for all samples.

From analysing the figures 11 and 12, and also the indicated values in table 5, it can be drawn the conclusion that the maximum average value of hardness on the direction of measurement I, in zones 2 and 3, was obtained for the sample CDT

For the direction of measurement II it can be observed that the maximum average value of hardness was obtained in zone 2 for the sample N and in zone 3 for the sample CDT.

The differences between the values of the hardness's can be explained by the different quantities of heat inserted in the material by the welding technology, the different way of heat diffusion to the surface of the sample, as well as the different number of passes needed to fill the canals

4. Conclusion

The following conclusions can be drown from the carried out experiments:

- The longest time claimed by the reconditioning by welding was in the process of depositing the layers for the sample HBT , explained by the need to remove half of the deposited layer prior to filing the next one;
- Applying the reconditioning by welding tehnique CDT, which consisted of increasing the value of heat input used for the deposit of each layer has conducted to the reduction of the number of layers compared with the technique N and the tehnique HBT, which will materialize in a shorter time and a lower cost for making the repairs;
- By changing the technique applied for the reconditioning by welding, dimensional changes appear in the size of the HAZ, as can be seen from the analysis of the figures 7,8 and 9 ;
- The applied technique for the reconditioning by welding leads to changes in the hardness values, so, destructive testing, such as as tensile testing or trying determinare resilience,are required when a certain method is chosen.
- The applied technique has considerable effects on geometrical elements of the seam, B, p, h as can be seen from the analysis of table 5.

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