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Gas metal arc welding in refurbishment of cobalt base superalloys

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Abstract. Refurbishments of superalloys which are used in manufacturing gas turbine hot components usually consists of removing cracks and other defects by blending and then repair welding in order to reconstruct damaged area. In this study, the effects of welding parameters on repair of FSX-414 superalloy, as the most applicable cobalt base superalloy in order to manufacture gas turbine nozzles, by use of Gas Metal Arc Welding (GMAW) technic were investigated. Results then were compared by Gas Tungsten Arc Welding (GTAW). Metallographic and SEM studies of the microstructure of the weld and HAZ showed that there are no noticeable defects in the microstructure by use of GMAW. Also, chemical analysis and morphologies of carbide in both methods are similar. Hardness profile of the GMAW structure then also compared with GTAW and no noticeable difference was observed between the profiles. Also, proper tensile properties, compared with GTAW, can be achieved by use of optimum parameters that can be obtained by examining the current and welding speed. Tensile properties of optimized condition of the GMAW then were compared with GTAW. It was seen that the room and high temperature tensile properties of the GMAW structure is very similar and results confirmed that changing the technic did not have any significant influence on the properties.

1. Introduction

After developing some tradition kind of cobalt-based superalloys such as X-40, X-45 and Mar-M 509, an advanced type of them was patented by General Electric (GE) Company in 1968-69, which is called FSX-414 that always used for manufacturing of many types of gas turbine nozzles [1]. Because of its chemical composition, corrosion resistance of FSX-414 superalloy is so high that is used without protective coatings in manufacturing of gas turbine component. Since FSX-414 alloy has good welding capability and this advantage give us to correct its defects like casting defects or service conditions defects by welding [2]. Gas turbine nozzles, similar to other parts of turbine, because of severe condition of operation may degrade and many types of defects can be occurred on them. Therefore, they should be repaired. Welding is one of the most common methods for repair of the turbine components. Welding is used for both defect repair and manufacturing. Among many methods of welding, Gas Tungsten Arc Welding (GTAW) is the most important technic. A pre-treatment should be performed before welding to prepare the structure of superalloy. Solution treatment is usually done at temperatures around 1200°C for some hours. In addition to GTAW, Gas Metal Arc Welding (GMAW) is an advanced technic that is widely used for repairing of ferrous and non-ferrous industrial components and materials [3]. Widespread usage of the GMAW is related to high flexibility of the process and the potential for performing automatic and robotic [4]. In recent years, Using of GMAW in gas turbine industry is increasing. The reason is to easy use of GMAW in all positions, being multipurpose and applicable. Weld quality depends to some different parameters such as current, feeding rate, welding speed, protective gas and also welding pool that can be affected by deposition rate. Heat transfer and fluid current in GMAW weld pool is similar to GTAW and in recent decades is widely studied. In GTAW process, metal deposition in weld pool can achieve a flat surface. In contrast with GTAW, in GMAW process, collision of droplets to pool can create free surface and deformed pool affects the distribution of arc current and heat transfer from arc to pool [5].

In previous studies on GMAW, it was seen that in addition to welding parameters, like current, voltage, welding speed and filler material, there are some other parameters that can influence on the welding quality: composition of protective gas and welding technic. High rate of deposition in GMAW can accelerate the repair rate of damaged components. Since rapidity of parts delivery to power plant is one the most important factors of repair, it may be interesting for repair service companies that use GMAW as repair welding technic instead of or in addition to GTAW.

Therefore, in this study, optimization of GMAW method in repair welding of gas turbine nozzles, which is made of FSX-414 cobalt base superalloy, was evaluated and the results was compared with GTAW.

2. Experimental

As mentioned before, the aim of this study is to optimize the GMAW process specification and also comparison of the result with GTAW on the FSX-414 cobalt base superalloy with nominal composition of 53Co 29Cr 10Ni 7W 1Fe 0.25C 0.01B. Because in most cases of repair the surfaces should be reconstructed, an empty pool, as shown in Figure 1, was designed to assure that the volume of repair in the experiments are equal. To fill this, GTAW was performed according to its usual welding process specification, WPS, (Table 1) by use of FSX-414 as filler material with diameter of 1.2mm. GMAW parameters that were studied in this study were current and welding speed. The design of experiments is shown in Table 2.

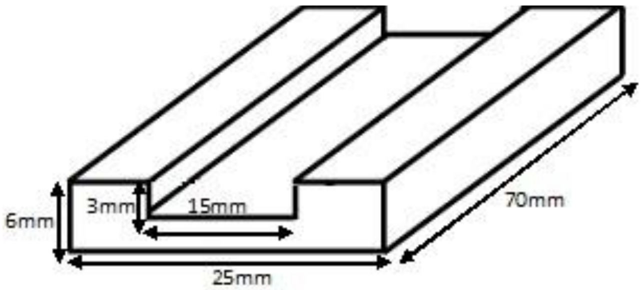


Figure 1. Schematic illustration of weld pool.

Table 1. WPS of GTAW used in this study.

Current (A)	Intermediate Temp. (°C)	Welding Speed (mm/min)	Voltage (V)	Sample Code
80-90	50-70	7-11	10-13	T1

Table 2. Design of experiments for GMAW.

Current (A)	Welding Speed (mm/min)	Code
85	14-16	M1
100		M2
85	24-26	M3
100		M4

Samples then were subjected to optical microscopy, and hardness test. Hardness test was performed according to ASTM E92 standard. SEM observations to analysis of the microstructure were performed using Philips-Tescan model. Finally, to study the mechanical properties of the samples, room and high temperature tensile test were done on the samples. Sub size samples that are proposed in an MSc thesis [6] was used to make samples. To achieve tensile samples, slabs with two similar pools, which are shown in Figure 2, were made and standard samples were taken off (Figure 3). Tensile test were performed in all weld condition. The thickness of the samples was around 1mm [6].

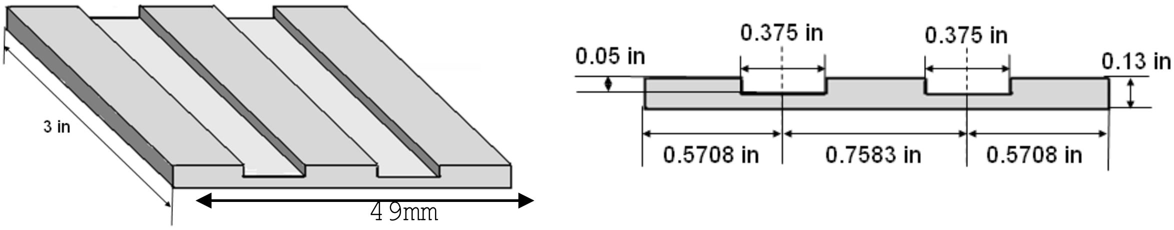


Figure 2. Dimensions of weld pool for tensile test.

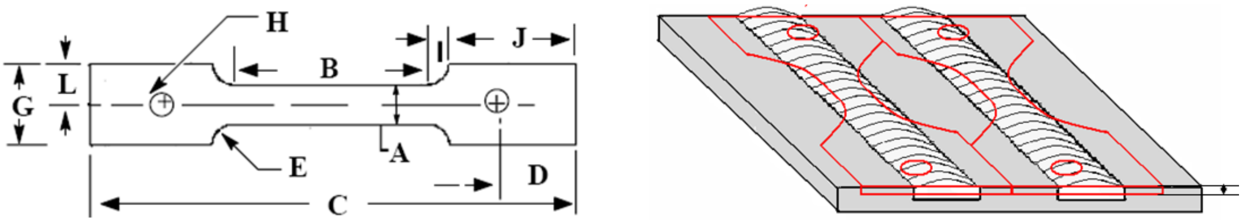


Figure 3. All weld tensile samples used in this study.

3. Results and discussion

3.1. Metallographic examinations

Figure 4 shows the optical microstructure of the weld and its interface with base material after GTAW. Also, because of good weld ability of the alloy, heat affected zone (HAZ) and crack was not observed.

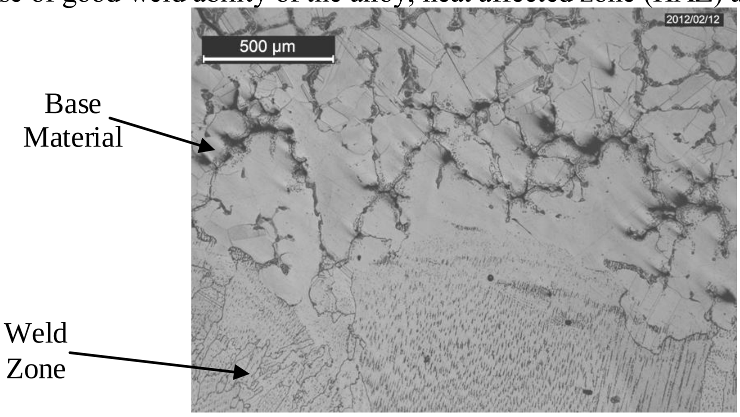


Figure 4. Microstructure of the FSX-414 GTAW.

Figure 5 (a) to (d) shows the microstructure of GMAW of the alloy in different conditions according to Table 2. A good condition in microstructure in terms of cracks, HAZ and also grain structure confirmed that high deposition rate and changing welding technic does not affect the microstructure, when comparing with GTAW (Figure 4).

As can be seen, GMAW welding parameters can affect the microstructure characteristics, but features that can reject the welding are not observed. Welding zone microstructure contains carbide precipitates and by use of cobalt base filler, microstructural characters of cobalt alloys, uniform dendritic structure and precipitates distribution, without any major defects in comparison with GTAW microstructure can be achieved.

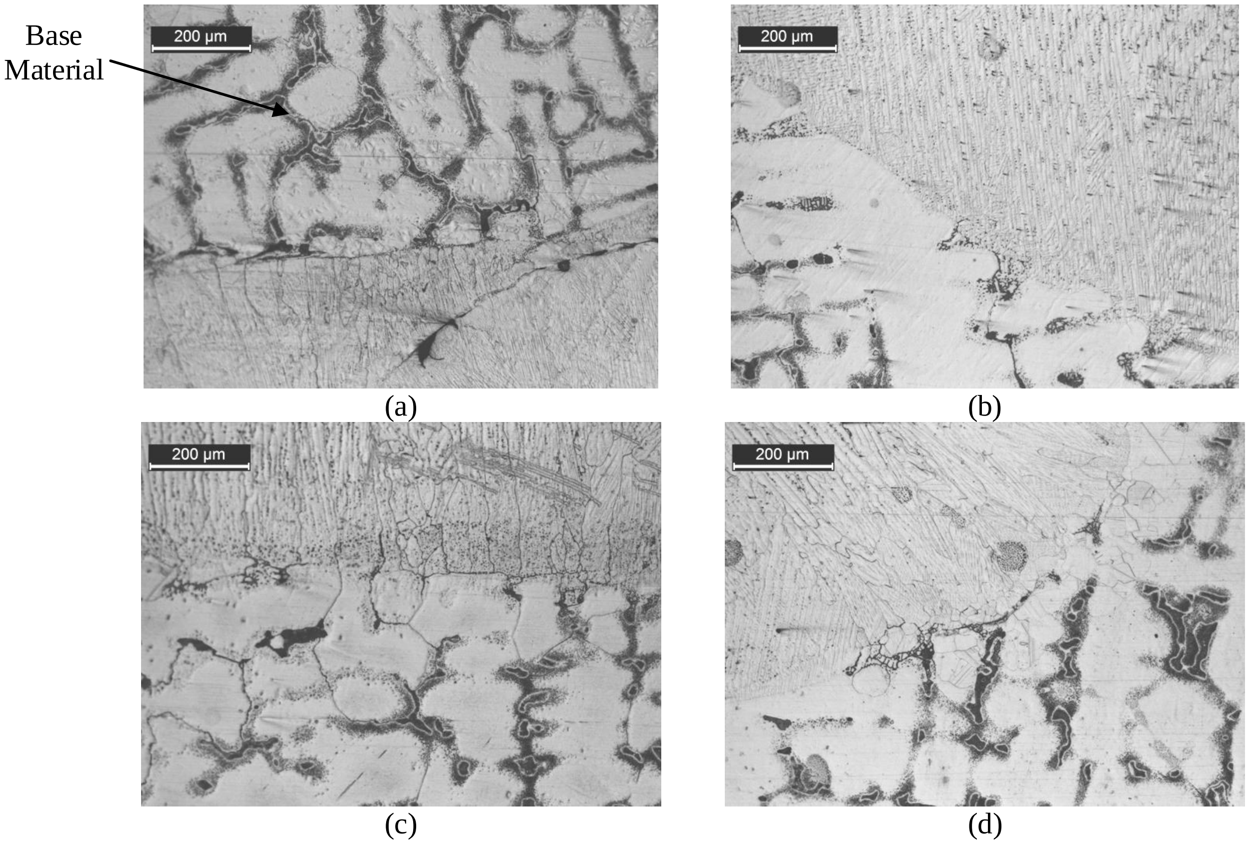


Figure 5. Microstructure of the GMAW of (a) M1, (b) M2, (c) M3 and (d) M4.

3.2. Hardness profile

Figure 6 shows the hardness profile of the GTAW sample (T1) as Vickers hardness measurement versus distance from weld center line. As seen, because of similarity of filler and base material, significant difference between them was not detected. Also, it can be seen that in some distances, hardness of the filler is higher than base alloy. This was referred in previous studies [7].

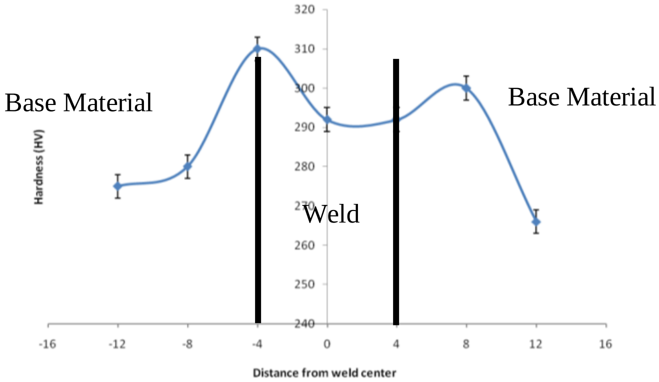


Figure 6. Hardness profile of GTAW microstructure.

Figure 7 illustrates the hardness profile of the GMAW microstructure in different welding conditions. Lines in graphs separate the weld zone and base material. In comparison with center line of the weld and adjacent zones, this is clear that decrement in hardness properties is not significant and this again confirms that replacement of GTAW with GMAW does not affect the weld mechanical properties. It can be observed that by use of high amount of current (samples M2 and M4), hardness profile of the weld and base microstructure has lower difference and increment of welding speed can improve the properties. Also, high welding speed can reduce heat input to the parts and high amount of current can form suitable fusion without any significant microstructural defects in GMAW. According to the above explanations, one can optimize the GMAW technic by use high amount of current and welding speed (M4 sample). In next part, tensile properties of T1 sample (GTAW) and M4 sample (optimized GMAW) will be compared.

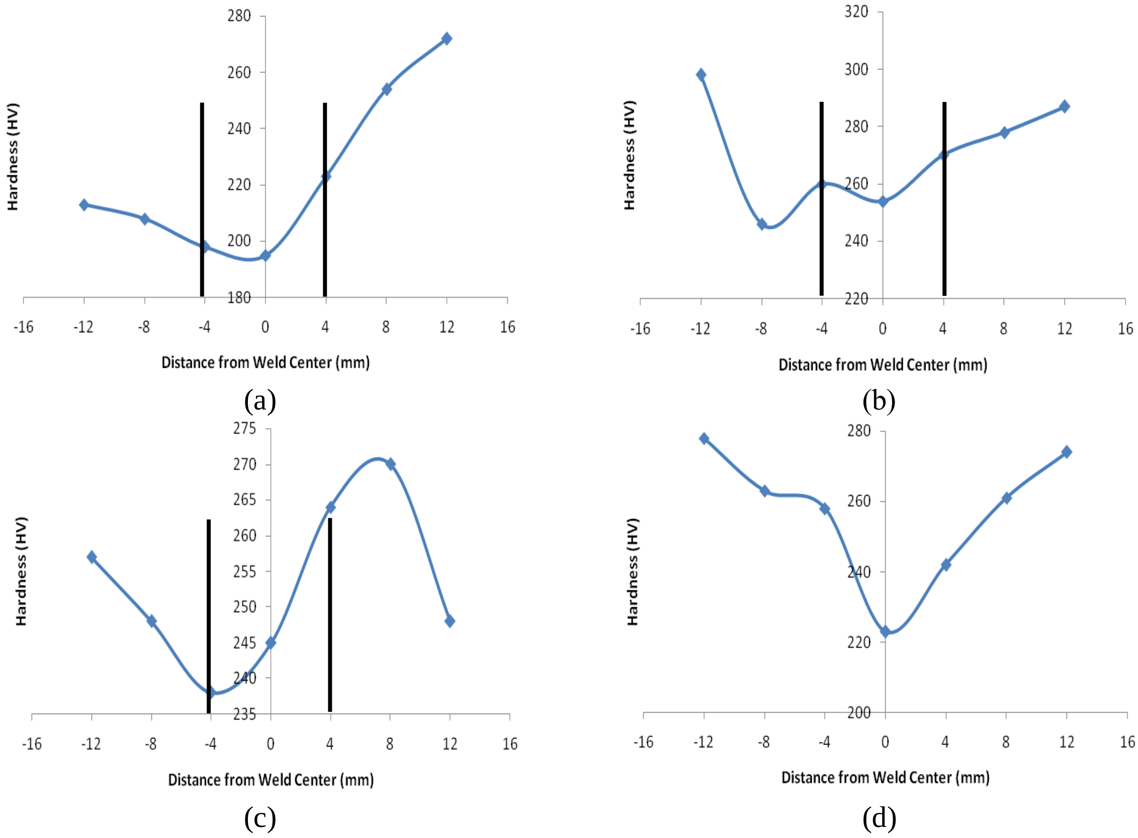


Figure 7. Hardness profile of GMAW of (a) M1, (b) M2, (c) M3 and (d) M4.

3.3. Tensile properties

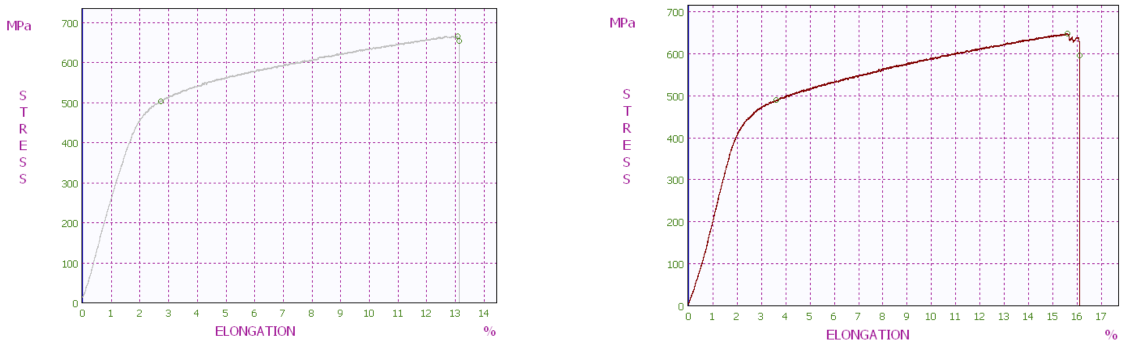
Figures 8 and 9 show the room and high temperature (600°C) tensile properties of the T1 and M4 samples. The results of mean value of three samples were also summarized in Tables 3 and 4. As mentioned before, mechanical properties of the samples are comparable and there is no significant difference between their properties. Suitable joint between filler and base material, absence of cracks in the microstructure and also margin size of HAZ in the microstructure can form proper mechanical properties. It is noteworthy that high temperature tensile properties of GMAW sample are much better than the GTAW sample.

Table 3. Room temperature mechanical properties of GTAW and GMAW samples.

Code	YS (MPa)	UTS (MPa)	Elongation (%)
T1	496	666	13.2
M4	488	648	16.1

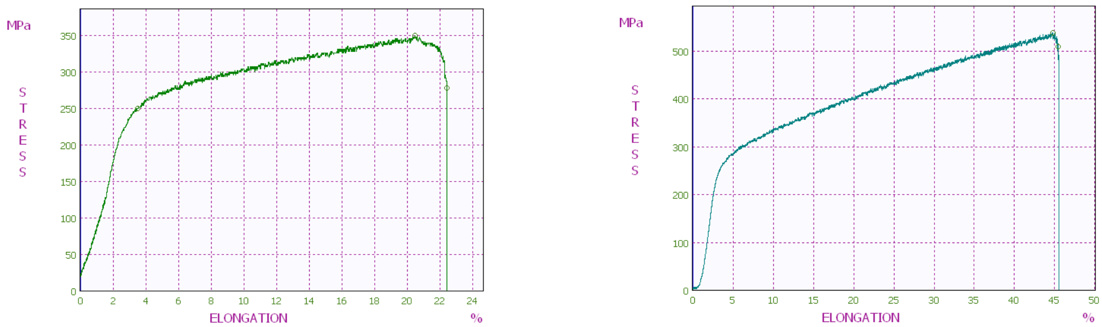
Table 4. High temperature mechanical properties of GTAW and GMAW samples.

Code	YS (MPa)	UTS (MPa)	Elongation (%)
T1	250	350	22.2
M4	275	525	45.5



(a) (b)

Figure 8. Room temperature tensile properties of (a) T1 and (b) M4 samples.



(a) (b)

Figure 9. High temperature tensile properties of (a) T1 and (b) M4 samples.

3.4. SEM observations

Figure 10 shows the SEM microstructure of weld and HAZ of the T1 sample. As seen in Figure 4, there is no noticeable defect in the microstructure. Carbides are created and distributed normally in the structure. Figure 11 shows the EDS analysis of the carbide in the weld zone. Arrow in Figure 10 shows the position of analysis. Also, Table 5 shows EDS analysis results of carbide. The results confirmed that $Cr_{23}C_6$ carbides are formed in the microstructure. Figure 12 shows the microstructure of the optimized GMAW sample (M4) and again no significant defects were observed in the microstructure. Similarly, Arrow in Figure 12 shows the position of EDS analysis. EDS analysis of the M4 sample confirmed that changing the technic and deposition rate do not influence on the formation of carbide's type (Figure 13).

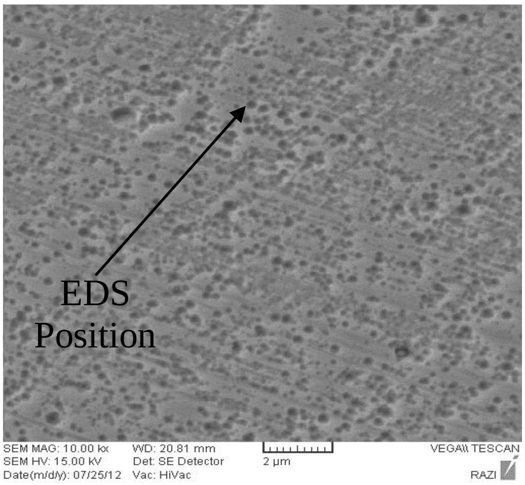


Figure 10. SEM micrograph of the GTAW sample (T1) MAG 10000.

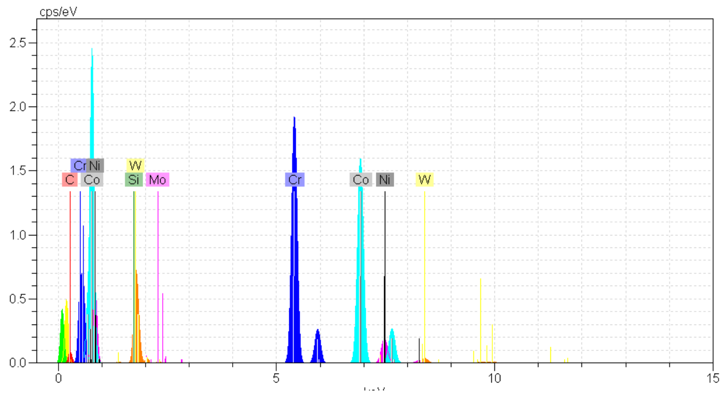


Figure 11. EDS analysis of the carbide in the weld zone of T1 sample.

Figure 12. SEM micrograph of the GMAW sample (M4) MAG 1500.

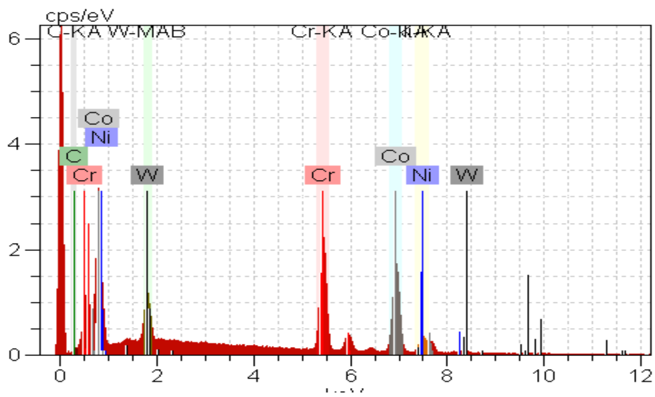


Figure 13. EDS analysis of the carbide in the weld zone of M4 sample.

Table 5. EDS analysis results of carbide in T1 sample.

Element	Series	Atomic Percent
Carbon	K	3.69
Chromium	K	32.94
Cobalt	K	54.01
Nickel	K	7.57
Tungsten	L	1.80
Total		100

4. Conclusions

Weld pools (samples) of FSX-414 cobalt base superalloy, with normal GTAW and four different cases of GMAW method are built up. By comparing the results of GMAW results, first process was optimized. The results were then compared with GTAW, as the most common technic of repair welding of gas turbine nozzles. The Results were summarized below:

1. Optical and SEM observations showed no significant defects like cracks, wide HAZ, etc. in the GTAW and GMAW microstructures.

2. Hardness profile of the GMAW samples showed that increasing the current can create more uniform profile it can improve the microstructural properties. So, welded sample with higher current and welding speed was selected as optimized GMAW sample.

3. Comparison of room temperature mechanical properties of the GTAW and GMAW samples showed that tensile properties of the samples are very close and also high temperature tensile properties of the GMAW sample is better.

4. These results confirm that GMAW with higher deposition rate can be a good method to replace GTAW in repair of superalloys without any significant decrease in properties.

5. Because of higher deposition rate in GMAW, one can improve the rapidity of repair cycle of the superalloys and reduce the defects.

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