焊剂带约束电弧特性的试验分析

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摘 要：通过向电弧两侧连续送入焊剂带以约束电弧的方法，对焊剂带约束电弧的特性进行了研究。结果表明，焊剂带靠弧柱区的热量被加热熔化，在稳定的焊接条件下，形成一个确定的焊剂带与电弧作用长度，其大小随电弧电压的减小，送带速度的增加而增大，这一参数直接影响着焊剂带约束电弧的形态，增加它可使电弧长度增长而宽度减小，进而可使焊缝的熔深增加而熔宽减小；焊剂带与电弧中心距离的减小可明显减小电弧的宽度，使焊缝熔宽减小而熔深增加；利用焊剂带约束电弧的特性可以实现超窄间隙焊接。

关键词：焊剂带约束电弧；电弧特性；超窄间隙焊接
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0 序 言

不同约束程度的电弧在一些焊接方法中都有应用，如埋弧焊，电弧在焊剂层下燃烧，整个电弧受到焊剂的固壁约束和焊剂熔化吸热的冷却约束，使电弧在较大的焊接电流时仍有较高的稳定性[1]；再如，用药皮焊条焊接时，通过选择合适的药皮成分和药皮厚度，焊接时在钢芯产生的电弧周围会形成一个药皮套筒，相当于对电弧的上半部分进行了固壁约束，可以提高电弧吹力，使电弧集中，改善熔滴过渡，在全位置焊接中有广泛的用途[2,3]。此外，超窄间隙焊接时，为了解决电弧沿间隙侧壁攀升的问题，采用在I形坡口两侧壁贴覆具有绝缘作用的焊剂片，对电弧加以固壁约束，能够保证良好的侧壁熔合[4]。

为了更有效地利用固壁约束电弧的特性，提出了一种焊剂带约束电弧的焊接方法[5]，将焊剂带沿焊丝两侧连续送入电弧区而熔化，焊剂带可对电弧产生一定的固壁约束作用，使电弧加热更集中。这一电弧特性可有效解决窄间隙焊接时坡口侧壁根部不易加热的问题，同时焊剂带具有类似于焊剂片防止电弧攀升的作用，研究焊剂带约束电弧的特性，便于将焊剂带约束电弧的方法应用于超窄间隙焊接。另外，该方法由于焊剂带送进速度和焊剂带与电弧中心距离可调，所以通过改变焊剂带送进速度或焊剂带与电弧中心距离，可获得受约束程度不同的电弧，有利于更深入地研究电弧受约束后的特性。

文中通过调节焊接参数，研究了不同参数对焊剂带熔化和约束参数的影响，以及不同约束参数对电弧形态和焊缝成形的影响，从而揭示了焊剂带在电弧区的熔化规律，及焊剂带约束电弧的特性。

1 试验方法及装置

如图1所示，焊丝经导丝管进入两块板式导电嘴的V形槽，并与工件接触引燃电弧，焊剂带经导带管在板式导电嘴的楔形面处被撑开，并在约束钢板的限制下沿焊丝两侧进入电弧区，在电弧热的作用下焊剂带熔化并进入溶池。焊剂带所用焊剂成分主要为大理石、萤石，及适量合金元素，焊剂带宽度为5mm，厚度为1～1.2mm，焊剂带中间是厚度为

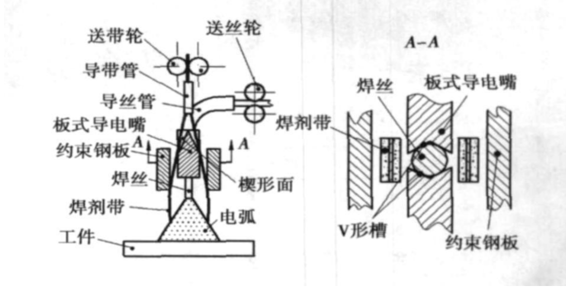

图1 焊接方法示意图
Fig.1 Schematic diagram of welding

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0.1 mm 的薄钢带,两面为压涂的焊剂。为了便于使焊剂带尽量靠近电弧中心以增强电弧的受约束程度,焊枪的板式导电嘴板厚取为 2 mm。另外,进入电弧区的焊剂带将受到电弧自身磁场的吸引而振动,从而导致电弧不稳定。为此,试验利用约束钢板对磁场加以屏蔽,同时,通过上下调节导带管将焊剂带在楔形面处撑开,再通过调节约束钢板与电弧中心距离的方法,使焊剂带受力以抵抗电弧自身磁场的吸引。

为了便于描述焊剂带对电弧的约束作用及电弧形态的变化,对电弧形态和焊剂带在电弧区的位置做了如下定义。如图 2 所示,c 为焊剂带与电弧的作用长度,简称作用长度;d 为焊剂带与电弧的作用距离,简称作用距离;L_a 为电弧长度,W_a 为电弧宽度,通过电弧摄像的方法可对上述参数进行测量。c,d,L_a 及 W_a 分别取为相同焊接参数时作用长度、作用距离、电弧长度、电弧宽度的平均值。如图 3 所示,电弧摄像时摄像头被置于电弧行进方向的一侧,电弧摄像采用 30 万像素的摄像机,其最大帧率为 30 帧/s。

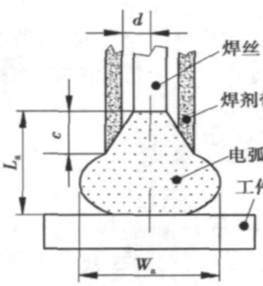


图 2 受约束电弧形态及焊剂带在电弧中的位置示意图

Fig.2 Schematic diagram of constricted arc morphology and position of flux strip in arc

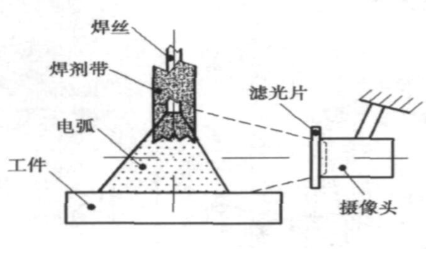


图 3 电弧摄像示意图

Fig.3 Schematic diagram of photographing arc

试验所用焊接电源为平特性,采用反极性焊接,焊丝为 H08Mn2Si,工件材料为低碳钢。

2 试验结果及讨论

2.1 焊接参数对焊剂带熔化和约束参数的影响

试验发现在一般情况下,焊剂带的熔化速度可以与送进速度保持相等,也就是说增大焊剂带送进速度,其熔化速度也相应增加。但当电弧电压和焊剂带作用距离变化时,焊剂带与电弧的作用长度将发生变化。图 4 为电弧电压与焊剂带作用长度的关系,随着电弧电压的增加,焊剂带作用长度逐渐变短。图 5 为送带速度与焊剂带作用长度的关系,随着送带速度的增加,焊剂带作用长度逐渐增长。图 6 为作用距离与焊剂带作用长度的关系,随着作用距离的增加,焊剂带作用长度逐渐增长。然而,当焊剂带送进速度超过某一临界值时,焊剂带熔化速度会小于焊剂带送进速度,以至焊剂带不能熔化完全并偏离电弧区。

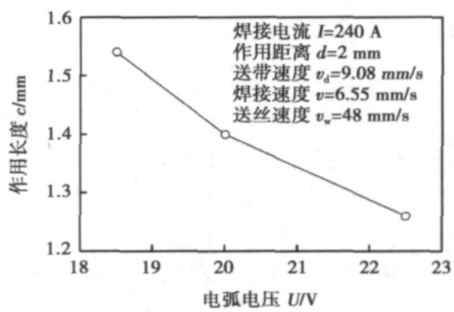


图 4 电弧电压与作用长度的关系

Fig.4 Relationship between arc voltage and action length

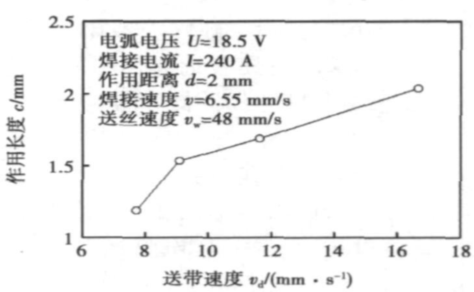


图 5 送带速度与作用长度的关系

Fig.5 Relationship between velocity of feeding flux strip and action length

电弧电压、焊剂带送进速度及作用距离对焊剂带作用长度的影响可做如下分析,焊接电弧的形态一般为钟形,如图 7 所示,电弧等温面的形状也呈钟形,靠近熔池的高温区较宽。当焊剂带与电弧的作

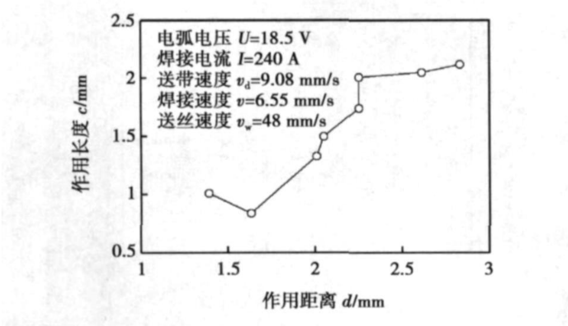


图 6　作用距离与作用长度的关系

Fig. 6　Relationship between action length and action distance

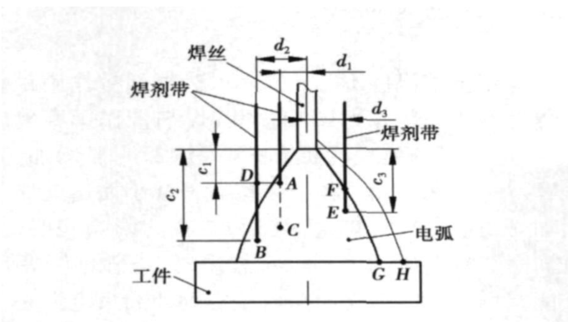


图 7　焊接工艺参数对焊剂带熔化和约束参数的影响示意图

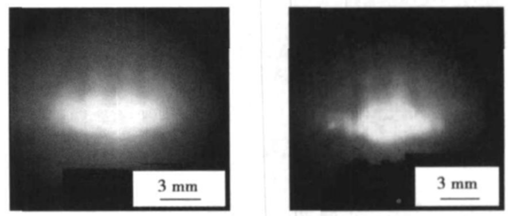
Fig. 7　Schematic diagram of influence of welding parameters on melting of flux strip and constricting parameters

用距离为 d_1 时，处于稳定熔化状态的焊剂带熔化端头位于电弧中的 A 点，若增加焊剂带送进速度，焊剂带熔化端头将由弧柱区温度较低的 A 点移至温度较高的 C 点，即作用长度增加，便于获得更多的电弧热量以提高焊剂带的熔化速度，保证焊剂带熔化速度与焊剂带送进速度相等。如果将焊剂带与电弧的作用距离由 d_1 增加到 d_2，焊剂带熔化端头就由弧柱区温度较低的 A 点移至温度较高的 B 点，即作用长度增加，保证焊剂带熔化速度与焊剂带送进速度相等。当焊剂带与电弧的作用距离为 d_3 时，处于稳定熔化状态的焊剂带熔化端头位于电弧中的 E 点，若增加电弧电压，电弧长度将变长，这将使焊剂带作用长度增长，同时电弧会由 G 点扩展至 H 点，电弧高温区加宽，电弧温度分布发生改变，导致 E 点温度升高，焊剂带熔化速度加快，这将使焊剂带熔化端头由弧柱区温度较高的 E 点移至温度较低的 F 点，即作用长度减小，从而保证焊剂带熔化速度与焊剂带送进速度相等。实际上，从图 4 可以看出，电弧电压增加时，焊剂带作用长度总体表现出略有减小的趋势。

可见，由于电弧的钟形特性，使焊剂带的熔化速度能与送进速度相等，改变焊剂带送进速度、焊剂带与电弧的作用距离或电弧电压，将直接影响焊剂带与电弧的作用长度。

2.2　约束参数对电弧形态的影响

以上分析可知，焊剂带与电弧的作用距离可以单独设定，而焊剂带的作用长度取决于作用距离、电弧电压及送带速度。作用距离和作用长度是影响电弧受约束程度的参数，通过摄像可观测到它们与电弧的相关关系。图 8 是两种不同作用长度下的电弧形态，可以看出当焊剂带作用长度较长时，电弧长度明显增长。



(a) c=0.1 mm　　(b) c=1.68 mm

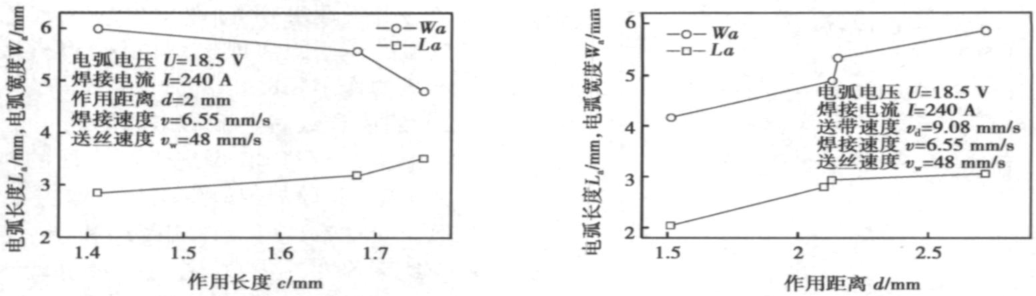
图 8　作用长度不同时的电弧形态

Fig. 8　Different arc morphology with different action length

对于等速送丝的熔化极电弧，电弧长度与电弧电压的对应关系取决于电场强度，若电弧的场强增加，在相同的电弧电压下，电弧长度将缩短。一般认为电弧受到约束后，电弧的电场强度将增大。图 9a 为焊剂带作用长度对电弧长度和宽度的影响，通过增加焊剂带送进速度，焊剂带与电弧的作用长度增长，电弧受约束程度提高，电弧宽度明显减小，但电弧长度不仅没有缩短，反而略有增长。这一电弧特性可用壁稳电弧加以解释，焊剂带作用长度相当于固壁，增加焊剂带作用长度，可使电弧中的部分带电粒子直接经焊剂带作用长度内表面进行传导，其效果等效于使弧柱电场强度减小，所以在其它焊接参数不变的情况下，焊剂带作用长度增加将使电弧长度增长。图 9b 为焊剂带作用距离对电弧长度和宽度的影响，通过减小焊剂带作用距离，电弧受约束程度提高，同时焊剂带作用长度将变短，导致焊剂带对电弧的壁稳效果减弱，所以电弧长度缩短，电弧宽度明显变窄。这表明在其它参数相同的情况下，减小焊剂带作用距离要比增加焊剂带作用长度对电弧宽度的减小更有效。

2.3　约束参数对焊缝成形的影响

减小焊剂带作用距离 d 或增加焊剂带作用长度 c 都能使电弧形态发生改变，导致电弧对工件加

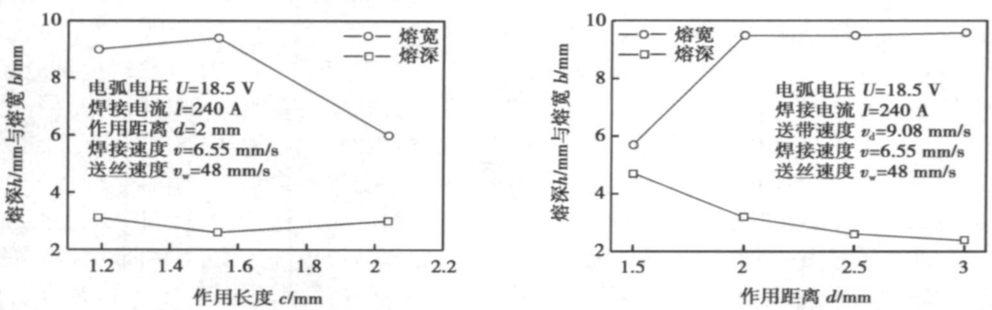


(a) 作用长度对电弧长度和宽度的影响　(b) 作用距离对电弧长度和宽度的影响

图9　约束参数对电弧形态的影响

Fig.9　Influence of constricting parameters on arc morphology

热效果发生变化,影响焊缝熔深与熔宽。图10a为焊剂带作用长度c对焊缝熔深和熔宽的影响,通过增加送带速度,焊剂带作用长度增长,电弧受约束程度提高,但焊缝熔深变化很小,在焊剂带作用长度$c>1.55$ mm的范围内,熔宽显著减小。在电弧热输入不变的情况下,送带速度增大,将使用于熔化焊剂带的电弧热量增加,而用于加热工件的电弧热量相对要减少,尽管电弧受约束程度提高,熔宽减小,焊缝熔深却基本保持不变。图10b为焊剂带作用距离对焊缝熔深和熔宽的影响,随着焊剂带作用距离的减小,电弧受约束程度提高,焊缝熔深明显增加,尤其在$d<2$ mm的范围内,熔宽显著减小而熔深显著增加。约束参数对焊缝熔深和熔宽的影响表明,只有当固壁将电弧约束到一定程度时,电弧能量密度才能获得明显的提高。这就是焊剂片约束电弧超窄间隙焊接时,电弧对侧壁根部易加热的主要原因。

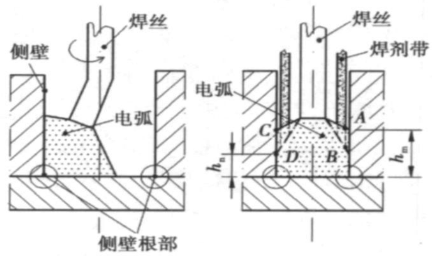


(a) 作用长度对焊缝熔深与熔宽的影响　(b) 作用距离对焊缝熔深与熔宽的影响

图10　约束参数对焊缝成形的影响

Fig.10　Influence of constricting parameters on weld formation

窄间隙焊接时坡口侧壁根部是电弧最难加热的部位[6],如图11a所示,常规窄间隙焊接一般都采用电弧旋转或电弧摆动的方法,以利于电弧加热坡口侧壁根部,但即使这样,也不能完全保证侧壁熔合良好。如图11b所示,在电弧不摆动或不旋转的情况下,两侧壁间距被尽量减小,使两侧壁位于电弧高温加热区内,同时将两条具有绝缘作用的焊剂带沿侧壁连续送入电弧两侧,通过增加送带速度,可使焊剂带熔化端头由A点移至B点,电弧由C点移至D点,即电弧对侧壁的加热高度由h_m减小到h_n,此时电弧被约束在较小的空间内,因而电弧的能量密度比其自由燃烧时的要高,电弧可直接作用于坡口侧



(a) 常规窄间隙焊接　(b) 超窄间隙焊接

图11　焊剂带约束电弧对超窄间隙侧壁加热示意图

Fig.11　Schematic diagram of heating ultra-narrow gap side-walls with constricted arc by flux strips

壁根部进行有效加热，保证侧壁熔合良好，图 12 为所得超窄间隙焊缝截面。

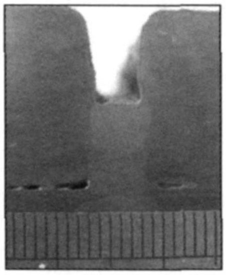


图 12　焊剂带约束电弧超窄间隙焊缝截面
Fig.12　Cross section of constricting arc ultra-narrow gap weld with flux strips

3　结　　论

(1) 焊剂带靠弧柱区的热量被加热熔化。降低电弧电压，加快送带速度或增加焊剂带作用距离，焊剂带作用长度都将增长。

(2) 增加焊剂带作用长度，将使电弧的长度增长而宽度变窄，进而使焊缝熔宽减小而熔深增加；减小焊剂带作用距离，将显著减小电弧的宽度，使焊缝熔宽减小而熔深增加。

(3) 焊剂带约束电弧具有加热集中且电弧受约束程度可调等优点，对解决窄间隙焊接时侧壁根部不易加热的问题具有独特的优势，并可实现超窄间隙焊接。

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(4) 与 MIG 焊相比，Hybrid 焊缝的铺展性更好，更适合于高速焊接。

(5) MIG 复合 2 kW 的激光能量后会增加平均电弧电压、减小平均电流。

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taken to reconstruct the three dimension shape of welding pool. Welding reflection map was established and was solved by using linear approximation, from which the depth iteration equation was obtained. It then presented the improved measure for this algorithm based on Kalman filter. Finally, the experiment validate that this algorithm is fast and effective.

Key words: shape from shading; pulsed gas tungsten arc welding; three dimension model of pool

Constricting arc characteristic with flux strips ZHENG Shaoxian, ZHU Liang, ZHANG Xulei, CHEN Jianhong (State Key Laboratory of Gansu Advanced Non-ferrous Metal Materials, Lanzhou University of Technology, Lanzhou 730050, China). p57—61

Abstract: Because constricted arc has many merits, such as high energy density and high velocity of plasma, it is applied in many welding fields. The characteristics of constricting arc with flux strips was studied by sending two pieces of flux strips into arc along both sides of the arc. The results show that flux strips are melted by heating of arc column under a stable welding condition, and certain action length of flux strips that act on the arc are formed on both sides of the arc, and the length will increase with the decrease of voltage and the increase of velocity of feeding flux strips. Action length can directly influence on the morphology of constricting arc with flux strips, and with action length increase, arc width will shorten and arc length will elongate, as a result the welds become deep and narrow; when the distance from the center of the arc to the flux strip is reduced, arc width will distinctly become narrow, and weld depth will become deep and weld width will become narrow; ultra-narrow gap welding can be achieved by use of the characteristics of constricting arc with flux strips.

Key words: constricting arc with flux strips; arc characteristic; ultra-narrow gap welding

Safety assessment of surface pit in penstock XU Zunping[1], CHENG Nanpu[1], LEI Binlong[2], CHEN Zhiqian[1] (1. Schoole of Materials Science and Engineering, Southwest University, Chongqing 400715, China; 2. Institute of Applied Engineering, Southwest Jiaotong University, Chengdu 610031, China). p62—64

Abstract: Based on the calculated results of finite element analysis and given the pit size, the criterion of safety assessment for in-service pressure vessels containing defects suggested by China was applied to assess the surface pit in penstock. The assessment wes carried out according to the CTOD (crack tip opeaning displacement) test result. Different assessment methods were used according to the pit distribution. The assessment results indicated that the assessment points are located within the safe region defined on the failure assessment diagrams. So the surface pit can be accepted.

Key words: penstock; pit; failure assessment diagram; safe assessment

Corrosion behavior of Q235 steel joint welded by different methots in the ammonium sulfite LEI Ali, FENG Lajun, ZHANG Min, ZHANG Shengchao (School of Materials Science and Engineering, Xi'an University of Technology, Xi'an 710048, China). p65—68

Abstract: In order to solve the serious corrosion of carbon steel welded joint in the ammonium sulfite during papermaking process, the corrosion behavior of the carbon steel welded joints, adopting shielded metal arc welding with J422 dectrode, TIG welding and CO_2 gas shielded arc welding, has been studied by three electrode electrochemical test and metallurgical structure analyses. The results show that the polarization curve of the Q235 steel joint welded by CO_2 gas shielded welding process in the 5%—11% ammonium sulfite at 20—80 ℃ is quite similar to the one of the base alloy, i.e. the two curves is close to each other, which means this kind of joint has the best corrosion resistance. The microstructure of Q235 steel joint welded by CO_2 gas shielded welding shows that the welded joint structure is consisted of massive amounts of pearlite and acicular ferrite, in which the fine perlites are dispersed in the ferrite.

Key words: galvano-chemistry; ammonium sulfite; welded joint; weld corrosion

Microstructure and properties of T joint by EBW-brazing hybrid welding LIU Xin, TAN Zhenyun, MAO Zhiyong (Key Laboratory of High Energy Density Beam Processing Technology, Bejjing Aeronautical Manufacturing Technology Research Institute, Beijing 100024, China). p69—72

Abstract: TA15 titanium alloy T joint obtained by EBW (electron beam welding)-brazing hybrid welding was investigated. The microstructure, element distribution and interfacial reaction were studied by means of scanning electron microscope, energy dispersive spectvoscope and X-ray diffraction. The bending properties of the joints both by hybrid electron beam welding with brazing and by electron beam welding were tested. The results showed that TA15 titanium alloy T joint was acquired by EBW-brazing hybrid welding with proper parameter. Element diffusion and interfacial reaction exist in the interface of electron beam welding and brazing. The plastic properties of the joint acquired by hybrid electron beam welding with brazing preceded the one only by electron beam welding. But the maximum intensity of pressure endured by the former is slightly lower than the later.

Key words: electron beam welding-brazing hybrid welding; T joint; microstructure; bending properties

Modeling and analysis of droplet forming in gas metal arc welding short circuiting transfer WANG Guangwei, CAI Yan, HUA Xueming, WU Yixiong (Laser Processing Laboratory, Shanghai Jiaotong University, Shanghai 200240, China). p73—76

Abstract: The conception and modeling of droplet forming in gas metal arc welding short circuiting transfer was proposed. By virtue of Micro Focus High Speed Photography technique and digital image processing technique, the gravitation, electromagnetic force and the maintaining force rooted in the surface tension of the little guttate metal in droplet forming process were analyzed and calculated